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ROMANCE OF THE SUN

DRAWING OF SOLAR ECLIPSE AS SEEN ON AUGUST 9, 1896,
FROM THE KUNNEN PROMONTORY, NORWAY, BY M. PROCTOR

Romance of the Sun

By MARY PROCTOR, F.R.A.S., F.R.Met.S.

(Daughter of the late Richard A. Proctor)
Author of "The Romance of the Comets," "Evenings with the Stars," "Stories of Starland," "Giant Sun and His Family," "Legends of the Stars," "The Children's Book of the Heavens," Etc.

ILLUSTRATED

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Dedicated

to

GEORGE ELLERY HALE,
D.Sc., F.R.A.S.

Hon. Director of the Solar Observatory,
Mount Wilson, Cal., U.S.A.

TECHNOLOGY & SCIENCE

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Preface

THE Romance of the Sun is one which should appeal to us all. There is the Sun beaming down on us, day after day, yet how many ever give it a thought? An attempt has been made in this book to show, from the popular standpoint, some of the wondrous revelations concerning the Sun, discovered by means of photography and the spectroscope. Special reference has been made to total eclipses of the Sun, when the corona becomes visible; and descriptions have been given of personal experiences in seeing this crown of glory which surrounds the Sun and can be seen only when the glare of sunlight is hidden by the Moon. The final chapter of the book contains an account of the total eclipse of the sun, which occurred on June 29, 1927, and descriptions are given by different observers, including the writer, of views obtained from an aeroplane, affording a doubly thrilling experience

With the kind permission of the Astronomer Royal, and the Directors of the Yerkes and Mount Wilson Observatories, photographs have been used

as illustrations. Moreover, the MS. has been read and many valuable suggestions made by Dr. A. D. C. de la Crommelin, for which the author feels greatly indebted.

MARY PROCTOR.

London, 1927.

ROMANCE OF THE SUN

INTRODUCTION

The night has a thousand eyes
And the day but one;
Yet the light of the whole world dies
With the dying sun.
—F. W. Bourdillon.

LET us go backward thousands of years, and stand beside our great ancestor as he watched the last expiring gleams of sunlight. What strange sensations must have swept through his bewildered mind as he saw the glowing orb of day rapidly vanishing from sight. Where had it gone? Would it ever return to cheer him with its warmth? Some such questions must have occurred to him as he watched the first sunset ever seen by mortal on our planet. One can imagine his feeling of overwhelming surprise and delight after the long hours of darkness during which he had watched the stars seemingly ascending and descending the heights of heaven, fading at the approach of dawn. A faint streak of rosy light heralds the splendour of sunrise, a spectacle so familiar to us that it usually passes unheeded, for we can imagine noth-

ing else. Yet picture that fancy, suggested long ago by Plato, of a man who had grown from maturity in some dark distance, and was brought on a sudden into the upper air to see the sunrise.

"What would his wonder be," as Carlyle wrote in his essay on "The Hero as Divinity," "his rapt astonishment at the sight we daily witness with indifference! With the free open sense of a child, yet with the ripe faculty of a man, his whole heart would be kindled by that sight, he would discern it well to be Godlike, his soul would fall down in worship before it."

Is it any wonder temples were erected in honour of the Sun, a god apparently endowed with the power of bestowing or withdrawing his light and heat at will? These temples of old are now replaced by solar observatories containing elaborate instruments devised for the purpose of studying not only the surface of the Sun, but enabling the astronomer to penetrate, as it were, beneath the cloud-like layers of gaseous material which veil its hidden splendour from view. Were this veil removed the Sun would dazzle us with its brilliancy, glowing with a bluish hue, and, moreover, it would rank among the hottest stars in the prime of life. At present it is but a middle-aged dwarf as denoted by its yellowish tint. No longer is it the "Giant

Sun" Sir John Herschel described, in the reference he made to "Giant Size and Giant Strength" as "ugly qualities without beneficence. But the Sun is the almoner of the Almighty, the delegated dispenser to us of light and warmth, as well as the centre of attraction, and as such the immediate source of all our comforts, and indeed of the very possibility of our existence on earth."

While the Sun is no longer regarded as a giant, having dwindled to medium size among its peers in stellar realms, owing to modern research regarding the constitution of stars, yet it remains the most important star in the heavens for us. To liken the orb of day to the twinkling points of light we see at night seems an exaggeration, but, as a matter of fact, we are nestled so near to the Sun, from a comparative point of view, that the stars appear insignificant in consequence. In reality many of the stars are stupendous as compared with our own bright day star, the Sun. Were it removed to the distance of even the nearest star, it would decrease in size and splendour, until finally on arriving at the position occupied by Alpha, a star in the constellation of the Centaur, it would appear but a star of the second magnitude, a mere point among the countless millions which begem the nocturnal sky. On the other hand, were we

living on Mercury, the next door neighbour planet to the Sun, we should see the orb of day blazing in the Mercurian skies with a disc seven times as large as we see it here. The heat would be intolerable, and life as we know it an impossibility. As it is, we are placed at a distance from the Sun which enables us to bask in its light and heat with comfort. Nevertheless, cut off the rays of sunlight for a single month and all life would cease on our planet.

To the unaided eye, the Sun presents the appearance of a round, white disc, a little more than half a degree in diameter. If we can picture to ourselves a circlet of suns around the horizon, seven hundred would be required to complete the circle. When the Sun is observed with a telescope, its surface appears fairly uniform, with a slight darkening at the edge. Moreover, black spots are seen at times on the disc. Galileo perceived these markings when he turned his improvised telescope in the direction of the Sun, and he supposed they were clouds floating in the solar atmosphere. This aroused the wrath of the philosophers of that day, who objected strongly to the idea that any defect could be found on the surface of the Sun. In fact, for a long time the possibility of the existence of sun spots was earnestly denied by the students of

PHOTOGRAPH OF THE SUN AND SUNSPOTS, JANUARY 25, 1920.
ROYAL OBSERVATORY, GREENWICH

the philosophy of Aristotle. They gravely urged that it was impossible that the Eye of the Universe should suffer from ophthalmia, and it is related that when Scheiner communicated his discovery of the solar spots to the provincial of his order, the latter, who was an earnest believer in Aristotle, answered: "I have read Aristotle's writings from beginning to end many times, and I can assure you that I have nowhere found in them anything similar to what you mention; go, therefore, my son; tranquillise yourself; be assured that what you take for spots in the Sun are the faults of your glasses or of your eyes."

Despite the defenders of the belief held by Aristotle, Galileo continued his labours, until finally he lost his eyesight, from viewing the Sun so often without the use of dark glasses now commonly employed. As will be shown later on, the existence of sun spots has been proved conclusively, and their study has afforded many marvellous revelations. By watching the sun spots it has been possible to ascertain from their position on the photosphere (a shell of incandescent clouds, formed by the condensation of the vapours which are exposed to space), that the Sun revolves upon its axis once in about twenty-five and a quarter days.

At the time of a total eclipse of the Sun, when the Moon hides its light completely from view, we are enabled to see a rose-coloured stratum of gaseous matter to which has been assigned the name of chromosphere, a word derived from the Greek word "chroma" (colour), meaning colour sphere. It is so called because it is brilliantly scarlet, and this colour is due to the hydrogen gas which is its chief component. In structure it is like a sea of flame covering the photosphere to a depth of from 5,000 to 10,000 miles, and seen through a telescope at the time of a total eclipse of the Sun, it has been described as resembling a "prairie on fire." Jets of heated hydrogen ascend through the spaces between the clouds of incandescent gas in the photosphere upon which the chromosphere rests, and these solar flames ever changing in appearance sometimes resemble spray from a fountain, or the interlacing branches of trees, or fiery rain falling upon the blazing surface of the Sun beneath. These flames can be seen outlined against the pearly light of the corona, that mysterious circlet which surrounds the Sun and is visible only during the few fleeting moments of a total eclipse of the Sun. It forms a fitting crown of glory for that orb which sways the planets by

its attraction, warms them by its fires, and illuminates them by the splendour of its light.

These are a few main facts about the Sun, the mere outline of a romance which is being slowly evolved by Argus-eyed science—the eye of keenness, the eye of patient watchfulness, and the eye of artistic truth. The vast importance attached to the study of the Sun is due to the fact that it is the only star lying near enough to the Earth to permit of detailed investigation. The knowledge thus derived gives us remarkable evidence regarding the evolution of stars, the Sun denoting the stage of maturity. Moreover, it is a typical star giving an intimation of what the stars are made of, and revealing the interesting fact that many of the elements forming the composition of the Earth are to be found in the Sun and stars, since

> "We are but parts of one stupendous whole
> Whose body Nature is, and God the soul."

CHAPTER I

THE YARDSTICK OF THE UNIVERSE

IF WE are planning a journey to a far-off land, it is essential that we take the trouble to ascertain its distance and position from the geographic standpoint, and the time required to reach our destination. The means of conveyance is also an important item, if the traveller is intent on arriving at his destination in the minimum of time. According to the latest estimate, the distance of the Sun is 92,900,000 miles. A journey to the Sun on the wings of thought would transport us across that vast abyss in a second of time. If one were to try to walk such a distance, at the rate of four miles an hour, keeping up this speed for ten hours every day, if he had started on his journey six thousand years ago, he would still require about three hundred years more to reach the terminus.

If one can imagine a celestial railway extending from the Earth to the Sun, the journey to the Sun, even if the train ran continuously at the rate of a mile a minute, would take over one hundred and

seventy-five years. An airplane travelling at twice the speed of the train would not reach its destination until nearly eighty-eight years had elapsed, by which time the youngest passenger at starting, a boy, let us say, ten years old, would have become a hoary veteran. An explosion on the Sun would not be heard by us until fourteen years after it actually occurred, or, to reverse the illustration, if a cannon-ball were to move uniformly with the same speed as when it left the muzzle of the gun fired in the direction of the Sun from planet Earth, the ball would not reach its objective for nine years, and the sound of the explosion would not be heard until five years later. This would have been distressing news to the Sun-worshippers of old, had they known that the sound of their prayers required fourteen years to reach their Sun god.

Even if it were possible to touch the surface of the Sun with the tip of the finger, the rash mortal who made the venture would never know that his finger had been burned in the process, for, according to the experiments made by Helmholtz and others, a nervous shock is communicated to the brain at the rate of about one hundred feet per second, or 1,637 miles a day. Since the Sun is nearly 93 million miles away, more than one hun-

dred and fifty years must elapse before the sensation of burning would pass from the tip of the finger to the brain of the venturesome mortal. According to Professor A. C. Young, "If the Earth could be suddenly stopped in her orbit and allowed to fall unobstructed toward the Sun under the accelerating influence of his attraction, she would reach the centre in about two months. I have said if she could be stopped, but such is the compass of her orbit that to make its circuit in a year she has to move nearly nineteen miles a second, or more than fifty times faster than the swiftest rifle-ball; and in moving twenty miles her path deviates from perfect straightness by less than one-ninth of an inch" (*The Sun*, p. 37, A. C. Young).

Passing from fanciful considerations to actual fact, the task of estimating the actual distance of the Sun is one of the most important and stupendous problems confronting the astronomer. This factor represents what has been termed the "Yardstick of the Universe," and in dealing with such vast distances an infinitesimal error must result in corresponding larger errors in dealing with the distances of the planets from the sun, or that of the remote stars on the boundary of the universe as known to us at present. By means of new and

improved methods of research, these boundaries are rapidly being extended. Yet the oscillations of scientific opinion as to the actual distance of the Sun depending on estimates given by different authorities have varied from 95,000,000 to 91,000,000 miles, and, as already stated, are now accepted provisionally at 92,900,000 miles. Yet if we consider the nature of the task undertaken by astronomers in this case, we can readily understand why their measurements should have differed somewhat widely from one another.

Let us picture to ourselves for a moment the central Sun, the Earth, and the path of the Earth around the Sun. Let us reduce the scale of the entire system so that the Sun is represented by a globe three yards in diameter, the Earth becomes a one-inch ball circling round that globe at a distance of about 325 yards. On this scale the diameter of the Earth's orbit (actually 186,000,000 miles) is reduced to somewhat more than a third of a mile. If we imagine the one-inch ball moving round the globe three yards in diameter, while turning on its axis once in a day, we find ourselves under a difficulty arising from the slowness of the resulting motions. We must wait a whole day before the one-inch ball representing the Earth has turned on its axis once, and a whole year before it has com-

pleted its circuit round the three-yard globe representing the Sun, which meanwhile has been forging ahead at the rate of about one yard in seventeen hours. Within a minute our miniature system would have advanced 1,140 miles in space, vanishing almost literally in the twinkling of an eye. Therefore, we must not only reduce the size of the Sun, Earth, and its orbit, but the time-scale as well, but not in the same degree. Otherwise, we should have the one-inch ball circling round its orbit, a third of a mile in diameter, sixteen times in a second, and turning on its axis five thousand times in a second, so we must reduce the days to seconds.

Now we have a picture of the one-inch globe circling once in rather more than six minutes about a globe of fire three yards in diameter, one-sixth of a mile from it, and turning on its axis once in a second. We must further picture this one-inch globe inhabited by millions of mortals far too small to be seen with the most powerful microscope, a few of the more ambitious highbrows actually undertaking the task of determining from their swiftly rotating tiny home in space, as it rushes in its orbit around the globe of fire, 325 yards from them, what may be its actual distance! Yet such in miniature are the conditions under

which the astronomer labours when he endeavours to determine the distance of the Sun from the Earth. The wonder is that any idea of the Sun's distance should be obtained at all, considering the difficulty of the problem and its accurate solution. Nevertheless, although the problem is difficult, yet there is no mystery about its solution.

The principle involved is simply the method adopted by surveyors in mapping out a country, or measuring the height of some distant mountain peak or the width of a river, without taking a tape for the purpose from one side across to the other. When a surveyor has to determine the distance of an inaccessible object, he proceeds as follows. First, a base line of convenient length is selected and very carefully measured—that is, he observes its length and the direction in which it lies. It must not be too short in comparison with the distance of the inaccessible object, otherwise the least error made in observing the bearings of the object would result in corresponding errors in the resulting determination of the distance.

But how can the astronomer find a base line of sufficient length for determining the Sun's distance upon our Earth, which is quite a tiny speck in comparison with the vast distance which separates us from the Sun? As in terrestrial survey-

ing, it is necessary that he should make the length of the base line commensurable with the distance to be calculated, so he must search for a base line of suitable length to determine the distance of the Sun. Let it extend from one side of the Earth to the other, by means of a tunnel passing through the equator; the observers stationed at each end would then be separated from each other by a distance of nearly eight thousand miles. Such a base line, when compared with the distance of the Sun, would be equivalent to measuring the height of a steeple five miles off, from a base line two feet in length. The height would not be appreciable or measurable, yet such is the nature of the difficult problem confronting the astronomer when he attempts to measure the distance of the Sun from the Earth.

The equivalent of the distance of the Sun from the Earth is the quantity known as the solar parallax,—*viz.*, the angle subtended by the radius of the Earth at the Sun. It is usually expressed in seconds of arc, having a value very close to 8″.80. If this is converted into circular measure and divided into the radius of the Earth, expressed in miles, the quotient gives the Sun's distance also in miles. This is a very puzzling matter if we

were to try to describe it fully, but the principle of the method is not at all difficult.

We have been provided with two eyes to aid us in estimating distances. Close one eye, while looking at a ruler held in front of you and notice its position with regard—let us say—to a picture on the wall. Now open that eye and close the other, then note the changed position of the ruler in connection with the picture. That is its parallax (Greek for a shift) relative to the picture. Thus, in astronomical language, a near body, such as a planet, is displaced with reference to more distant bodies, when observed from different points of view. The nearer body has a parallax relative to the distant bodies, and all such determinations are called determinations of parallax. As we shall see in the next chapter, planet Venus supplied the most famous occasions for the solution of the problem, as this planet being only at about one-third the distance of the Sun, has a parallax relative to him. The consequence of this parallax is, then, that the time at which Venus appears to enter upon and leave the Sun, and the duration of the transit, depend upon the place on the Earth which is chosen as a station from which to make the necessary observation. "In transits of Venus we observe, not the parallax of the Sun directly,

but the difference of parallax between Venus and the Sun; so that to complete our problem it is necessary to know what proportion the distance of Venus bears to the distance of the Sun." * As shown in the following chapter, the direct method of work on the solar parallax, is mainly the use of an exterior planet as the stepping stone, affording a great number of advantages. "The planet is nearest and its parallax greatest, when it is in opposition to the Sun, visible all night, and observable in consequence after sunset and before sunrise. The planet can be compared with the stars about it, so that the whole parallax, and not the difference between two, can be measured. And, greatest advantage of all, the observations can be continued over weeks or months; failure at one moment can be repaired by success at others, and the astronomer is relieved of the disquieting anxiety lest a temporary breakdown in instrument or bad weather should ruin everything at a critical moment." † In the following chapter an account is given of Sir David Gill's work at Ascension showing how the planet Mars was pressed into service, and later on, the minor planets Victoria, Iris, Sappho, and notably the minute planetoid

**Astronomy*, p. 144. A. R. Hinks, "Home University Library."

† *Astronomy*, p. 145. A. R. Hinks.

Eros which made its début in astronomical circles, as it were, in 1898, for prior to that time astronomers were unaware of its existence.

"The Moon being the nearest of all the heavenly bodies has the largest parallax. Its distance can therefore be determined with the greatest precision by measurement. Even Ptolemy, who lived only one or two centuries after Christ, was able to make an approximate measure of the distance of the Moon. But the parallax of a planet is so small that it can be determined only with the most refined instruments." (The method used for finding the distance and parallax of the Moon is given in Section 239 of Young's *General Astronomy*, and the various methods for the determination of the Sun's horizontal parallax and distance, are given in Chapter XVII, of that same work.) While an account of these methods is far too technical for a popular treatise such as this, yet the method by which the Sun's distance is ascertained by means of what is termed "the equation of light," comes well within its limits.

The equation of light is the time occupied by light in travelling from the Sun to the Earth, and is determined by observation of the eclipses of Jupiter's moons or satellites. Every owner of a telescope delights to turn it on that planet, and

there is endless entertainment in watching the four large moons (for Jupiter has no less than nine, five of them, however, being beyond the reach of a small telescope), as they seem to play at hide-and-seek behind the giant planet. As a satellite revolves round Jupiter it often happens that the little body enters into the shadow of the great planet. As it has no light of its own, it disappears from sight until it has passed through the shadow and later emerges on the other side into the sunlight, making it possible for us to see it again. We can watch these eclipses, which prove most entertaining in the way the satellites have of suddenly appearing and disappearing from sight. The movements of Jupiter's satellites are now so well known that the moment of eclipse can be predicted. The almanacs will tell when a little moon should disappear, and when it is due to return again to visibility.

However, the satellites gave astronomers a great deal of trouble, some three hundred years ago, because they would not keep time, sometimes appearing or disappearing about eight minutes too soon or too late. They seemed most unreliable until the reason for their peculiar behaviour was discovered. It was in 1675 that Roemer, the Danish astronomer, after making a careful study of the

apparent waywardness of the little moons, solved the problem. When an eclipse occurred eight minutes before it was expected, Jupiter was at its nearest to the Earth, being at the part of its orbit when it is on the same side of the Sun as our planet; but when an eclipse took place eight minutes later than expected, then the planet was in the part of its orbit when it was on the opposite side of the Sun, and was therefore at its greatest distance from our planet. Roemer, as it were, put two and two together, arguing that light from the little moons required time to travel, the interval varying according to the different distances of the planet. It was the eclipses of the satellites which first suggested the conclusion that light has a measurable speed. When this was taken into account, then the occasional delay of the eclipses was found to be satisfactorily explained. Roemer's bold and original suggestion was rejected by most astronomers for more than fifty years—until long after his death—when Bradley's discovery in 1726 of the aberration of light proved that his solution of the problem of the eclipse delays and speeding-up was correct.

Aberration is the apparent displacement of a star, due to the combination of the motion of light with the motion of the observer. The principle

is simply as follows: when walking along briskly during a downpour of rain, when the rain is coming straight down, one does not hold his umbrella straight up, but slants it forward. The analogy of the umbrella as held in a downpour of rain is easily verified.

Supposing, however, the following experiment is made. Use a hollow tube instead of an umbrella, which necessitates standing in the rain without any protection overhead—a mere trifle under the circumstances. Hold the hollow tube straight up, and watch the raindrops passing through the tube without touching the sides. However, should we walk briskly forward, still holding the tube upright, the drops of rain entering at the top of the tube will be seen to splash against the side. However, by slanting the tube at the proper angle the raindrops will pass through freely.

In the same way, if the Earth were motionless and an astronomer pointed a telescope so that it faced a fixed star, the rays of light from the star would come down through the telescope tube and emerge at the eyepiece. But the Earth is moving at the rate of about nineteen miles a second, so that it becomes necessary to slant the telescope by a minute angle. The rays of starlight after passing through the object-glass, then emerge at

the centre of the eyepiece. Now the star seems to lie in the direction to which the telescope is pointing, which is not its real direction. And it seems to undergo an annual shift of position as the Earth circles round the Sun! *This* was the problem which puzzled Dr. Bradley, and it meant two or three years of hard work before he was able to find the solution—*viz.*, that the phenomenon was due to the combined motion of light and the Earth.

As so often happens, he discovered the solution accidentally. To quote his own words: "At last, when I despaired of being able to account for the phenomena which I had observed, a satisfactory explanation of them occurred to me all at once when I was not in search of it." He then goes on to relate how he had accompanied a pleasure party in a sail up the Thames. The boat in which they were was provided with a mast, which had a vane at the top of it. A moderate wind was blowing as the party sailed up and down the river, but Dr. Bradley remarked that every time the boat put about, the vane at the top of the boat's mast shifted a little, as if there had been a slight change in the direction of the wind. Finally, he asked the boatmen why it was that the wind seemed to shift so regularly every time they put about. They told him that the *wind* had not shifted, but

that the apparent change was due to the actual change in the direction of the boat, assuring him that the same thing invariably happened in all cases. Like most problems, that of the aberration of light seemed very simple when the answer was obtained.

The Earth, moving in an orbit nearly circular, may be compared to the boat, and it is clear that an observer on that earth-boat so to speak, will see a star at the pole of the ecliptic always displaced by the same amount, but in a direction continually changing. It must therefore appear to describe a little circle during the course of the year. The star selected for observation was Etanin (Gamma Draconis) which passes almost exactly through the zenith of Greenwich.

It was most important that Dr. Bradley should have a long telescope commanding a wide field of view for making his observations, and in his book, *Astronomical Discoveries*, Professor H. H. Turner tells the story of an obliging aunt who allowed her nephew to cut holes in the floor and roof of her house for this purpose. The object-glass end of the improvised telescope was out on the roof, and the eye end down in the coal cellar, and it was here that Bradley made the observations which led to his important discovery.

The motion of the Earth about the Sun, combined with the velocity of light, produces the well-known effect of the aberration of light, which causes all the stars to appear to move in little ellipses during the course of the year. "The size of the effect can be measured; the velocity of light can be measured independently in the laboratory; and from the two results we may deduce the velocity of the Earth in its orbit. Then knowing the length of the year, it becomes a simple matter to find the size of the orbit and the distance of the Sun." *

* *Astronomy*, p. 148. A. R. Hinks.

CHAPTER II

VENUS ON THE FACE OF THE SUN

WHEN Venus passes between the Sun and the Earth, so that it is seen projected on the face of the Sun, we have what is called a transit of Venus. The first calculated transit occurred in December, 1631, according to a prediction made by Kepler in 1629. Though he stated that the planet would not enter upon the Sun's disc till towards sunset, an astronomer named Gassendi, who had been successful in observing a transit of Mercury a month earlier, hoped for like success with the coming transit of Venus. He made elaborate preparations for the event at Paris where he was living at the time. Through a small aperture in a shutter the light from the Sun was admitted into a darkened room and the solar image, some nine or ten inches in diameter, was formed upon a white screen. A carefully divided circle was traced upon this screen, and the whole was so arranged that the image of the Sun could be made to coincide exactly with the circle.

He has given an account of his fruitless observations on this occasion in a letter written to an astronomer named Schickhard. He described how he intended watching the appearance of the Sun on the fourth and fifth days of December, "but an impetuous storm of wind and rain rendered the heavens invisible on both these days." On the 6th he continued to obtain occasional glimpses of the Sun till a little past three in the afternoon, but no indication of the planet could be discerned upon the disc he had drawn on the white screen. On the 7th he saw the Sun during the whole forenoon, but not a trace of the planet. It is now well known that the transit of Venus took place during the night between the 6th and 7th of December, and was therefore altogether invisible in Europe. Consequently, despite the elaborate preparations made by Gassendi, his efforts were uncrowned by success.

Kepler had stated that, after the transit of 1631, there would be none till the year 1761. According to his calculations, Venus, when in her inferior conjunction on December 4, 1639, would pass very near to the Sun's centre, but not quite near enough for a transit to occur, the planet passing *below*, that is, south of the Sun. Horrocks, a young and then unknown astronomer, having been

led to examine Kepler's tables of Venus, found that they were not absolutely accurate and that a transit would occur in 1639, Venus passing below the centre of the Sun, but not so low as to miss the Sun's disc altogether. The account he gives of his observations is full of interest and conveys some idea of the difficulties encountered.

> "Lest a vain exaltation should deceive me, and to prevent the chance of disappointment, I not only determined diligently to watch the important spectacle myself, but exhorted others whom I knew to be fond of astronomy to follow my example; in order that the testimony of several persons, if it should so happen, might the more effectually promote the attainment of truth, and because by observing in different places our purpose would be less likely to be defeated by the accidental interposition of clouds, or any fortuitous impediment."

Among the astronomers to whom he wrote was his friend Crabtree, the only one who heeded his suggestion, which may explain why Horrocks and Crabtree were the sole observers of the transit of Venus on this occasion. Horrocks was but twenty

years old when he calculated the transit, and those whom he exhorted may have been somewhat scornful regarding his enthusiasm in the matter, which may explain why he wrote to his friend Crabtree, as follows, when the time for the great event drew nigh:

> "I hope to be excused for not informing other of my friends of the expected phenomenon, but most of them care little for trifles of this kind, rather preferring their hawks and hounds."

Following the example of Gassendi, Horrocks admitted the light from the Sun through a small aperture in a shutter into a darkened room, with the additional aid of the telescope invented by Galileo, enabling him to make a close study of the surface of the Sun.

> "Having attentively examined Venus with my instrument [he wrote], I described on a sheet of paper a circle whose diameter was nearly equal to six inches, the narrowness of the apartment not permitting me conveniently to use a larger size. I divided the circumference of this circle into 360° in the

usual manner, and its diameter into thirty equal parts, which gives about as many minutes as are equivalent to the Sun's apparent diameter; each of these thirty parts was again divided into four equal portions, making in all 120; and these, if necessary, may be more minutely subdivided; the rest I left to ocular computation, which, in such small sections, is quite as certain as any mechanical division. Suppose, then, each of these thirty parts to be divided into 60″, according to the practice of astronomers. When the time of the observation approached I retired to my apartment and having closed the windows against the light, I directed my telescope, previously adjusted to a focus, through the aperture towards the Sun and received his rays at right angles upon the paper already mentioned. The Sun's image exactly filled the circle, and I watched carefully and unceasingly for any dark body that might enter upon the disc of light, on the 24th from sunrise to nine o'clock, and from a little before ten until noon, and at one in the afternoon,—being called away in the interval by business of the highest importance, which for these ornamental pursuits I could not with pro-

priety neglect.* But during all this time I saw nothing in the Sun except a small and common spot, consisting as it were of three points at a distance from the centre towards the left, which I noticed on the preceding and following days. This evidently had nothing to do with Venus.

"About fifteen minutes past three in the afternoon, when I was again at liberty to continue my labours, the clouds, as if by Divine interposition, were entirely dispersed, and I was once more invited to the grateful task of repeating my observation. I then beheld a most agreeable spectacle, the object of my sanguine wishes, a spot of unusual magnitude and of a perfectly circular shape which had already fully entered upon the Sun's disc on the left. . . . I immediately applied myself sedulously to observing it."

But the short winter day was rapidly drawing to a close, and the Sun would soon set. Only half

* Mr. Horrocks was a minister of Hoole, a very poor pittance, within four miles of Preston, in Lancashire, and noted for his skill in astronomy. He had a strange unaccountable genius, and he is mentioned with great honour by Hevelius on account of his discovery of Venus on the Sun, upon a Sunday; but being called away to his devotions and duty at church, he could not make such observations as otherwise he would have done.

an hour was available, but owing to the careful preparations Mr. Horrocks had made, not a second was wasted, and he was thus enabled to make some valuable measurements.

Horrocks was not the only observer of the transit of 1639, as we have already seen that he had informed his friend, William Crabtree, of the coming treat.

> "I have written [he says], to my most esteemed friend, William Crabtree, a person who has few superiors in mathematical learning, inviting him to be present at this Uranian banquet, if the weather permitted; and my letter, which arrived in good time, found him ready to oblige me. He therefore carefully prepared for the observation, in a manner similar to that before mentioned. But the sky was very unfavourable, being obscured during the greater part of the day with thick clouds; and as he was unable to obtain a view of the Sun, he despaired of making an observation, and resolved to take no further trouble in the matter. But a little before sunset—namely, about thirty-five minutes past three—the Sun bursting forth from behind the clouds, he at once began to observe,

and was gratified by beholding the pleasing spectacle of Venus upon the Sun's face. Wrapt in contemplation, he stood for some time motionless, scarcely trusting his own senses, through excess of joy; for we astronomers have, as it were, a womanish disposition, and are overjoyed with trifles, and such small matters as scarcely make an impression upon others; a susceptibility which those who will, may deride with impunity, even in my own presence; and if it gratify them, I, too, will join in the merriment. One thing I request: let no severe Cato be seriously offended with our follies; for, to speak poetically, what young man on earth would not, like ourselves, fondly admire Venus in conjunction with the Sun, *pulchritudinem divitiis conjunctum?*

"But to return, he from his ecstasy, and I from my digression, in a little while the clouds again obscured the face of the Sun, so that he could observe nothing more than that Venus was certainly on the disc at the time. What he actually saw in so short a space was as follows: In the apartment Venus occupied the right side of the Sun, being higher than its centre, and therefore in the heavens lower,

and on the left. She was distant at the aforesaid hour—namely, thirty-five minutes past three—a sufficiently appreciable space from the Sun's limb, but Crabtree's opportunity was so limited that he was not able to observe very minutely either the distance itself or the inclination of the planet. As well as he could guess, by his eye, and to the best of his recollection, he drew upon the paper the situation of Venus, which I found to differ little or nothing from my own observation; nor indeed did he err more than Apelles himself might have done in so rapid a sketch. He found the diameter of Venus to be seven parts, that of the Sun being 200, which, according to my calculations, gives about 1′3″.

"This observation was made near Manchester, called by Antoninus, Mancunium, or Manucium, the latitude of which Mr. Crabtree makes 52°24′, and the common tables 54°15′; the longitude 23°15′; or three minutes of time to the east of Liverpool, from which it is distant twenty-four miles.

"I wrote also of the expected transit to my younger brother, who then resided at Liverpool, hoping that he would exert himself on the occasion. This indeed he did, but it was

in vain; for on the 24th, the sky was overcast, and he was unable to see anything, although he watched very carefully. He examined the Sun again on the following day, which was somewhat clearer, but with no better success, Venus having already completed her transit.

"Venus was visible on the Sun throughout nearly the whole of Italy, France, and Spain; but in none of those countries during the entire continuance of the transit. But America!

"*O fortunatos nimium, bona si sua norint.*

"Venus! what riches dost thou squander on unworthy regions which attempt to repay such favours with gold, the paltry produce of their mines. Let these barbarians keep their precious metals to themselves, the incentives to evil which we are content to do without. But let us cease this complaint, O Venus! and attend to thee ere thou dost depart."

On which Horrocks bursts into strains of poetry, imploring Venus not to seek those barbarous regions for which, even as his eyes were gazing upon her, she was hastening. "But ah!" he sighs, "thou fliest,

" . . . and torn from civil life,
The savage grasp of wild untutored man
Holds thee imprisoned in its rude embrace.
Thou fliest, and we shall never see thee more;
While heaven, unpitying, scarcely would permit
The rich enjoyment of thy parting smile.
Oh! then farewell, thou beauteous queen! thy sway
May soften natures yet untamed, whose breasts,
Bereft of native fury, then shall learn
The milder virtues. We, with anxious mind,
Follow thy latest footsteps here, and far
As thought can carry us; my labours now
Bedeck the monument for future times
Which thou at parting left us. Thy return
Posterity shall witness, years must roll
Away, but then at length the splendid sight
Again shall greet our distant children's eyes." *

From the way in which Horrocks showed how the apparent place of Venus on the Sun's face must be affected by the observer's position, it is tolerably clear that he would have been led to perceive how observations made from different places could be used to determine the Sun's distance had time permitted him to correspond with other astronomers. As he himself asserts in his account of the transit of 1639—

"I had intended to offer a more extended treatise on the Sun's parallax; but as the sub-

*See Memoir by Rev. A. B. Whatton, pp. 134-135.

> ject appears foreign to our present purpose, and cannot be dismissed with a few incomplete arguments, I prefer discussing it in a separate treatise—'De syderum dimensione' —which I have in mind. In this treatise he proposed giving certain and easy methods of proving the distance and magnitude of the sun, doubtless anticipating the methods subsequently devised by Halley and Delisle."

Many years passed before the astronomical world began again to consider the subject of the next transit of Venus, which was due on June 5, 1761, and was considered of such importance as to induce Government to fit out large expeditions at a total cost of hundreds of thousands of pounds, sending them all over the Earth. Towards the close of the seventeenth century, the astronomer Halley, who during his stay at St. Helena had observed a transit of Mercury, published an interesting dissertation showing how a transit of Venus might be so observed as to afford means for determining the distance of the Sun. His method, the method of durations, is generally referred to by his name, and may be described as follows. Observers in different parts of the Earth see a transit of Venus under different circumstances; for

instance, the transit may be shorter or longer, according to the position of the observer. The time at which Venus appears to enter upon and to leave the Sun, and the duration of the transit, depend upon the place on the Earth which is chosen as a station from which to view the event. According to the station selected, an acceleration or retardation of about sixteen minutes may be found in the moment when we observe a particular phase of the contact. From these differences, if they be observed as they ought, the Sun's parallax may be determined to a small part of a second.

In two remarkable memoirs presented to the Royal Society of London in 1691 and 1716, Halley pointed out the great advantage of this method, and urged upon astronomers the necessity of providing for the complete observation of this phenomenon. To quote his own words:

> "I recommend this method again and again to those curious astronomers who (when I am dead) will have an opportunity of observing these things, that they would remember this my admonition, and diligently apply themselves with all their might in making this observation, and I wish them all imaginable success; in the first place, that

> they may not by the unreasonable obscurity of a cloudy sky be deprived of this most desirable sight, and then, that having ascertained with more exactness the magnitudes of the planetary orbits, it may redound to their immortal fame and glory."

Three years after he wrote the essay above referred to, Halley became Astronomer Royal, but was unable to see the transit of Venus, as he died on January 14, 1742, more than nineteen years before the transit occurred. As the time for the transit drew near astronomers began to examine carefully the motions of planet Venus, in order to ascertain how far the conditions on which Halley's computations had been based were actually fulfilled. A French astronomer, named Delisle, proposed another method in August, 1760, or less than a year before the transit took place, suggesting that observers might note the time at which transit began or ended (not necessarily observing the whole transit), and that differences observed in the epochs noted would give the means of measuring the Sun's distance. The observed epochs would all have to be expressed according to a uniform manner (all in Greenwich time, for instance, or all in Paris time); so that the longitude

of each observing station would have to be determined as well as the local time at which transit began or ended. But this accomplished, the method would avail as well as Halley's for determining the Sun's distance.

The actual history of the expeditions sent out is full of interest, but the results were marred by the peculiarity known as the black drop. Thus, Mr. Hirst, who observed the transit at Madras, where the Sun was at a considerable elevation, states that

> "At the moment of total immersion, the planet instead of appearing truly circular, resembled more the form of a Bergamot pear, or, as Governor Pigot then expressed it, 'looked like a nine-pin,' yet the part of the disc farthest from the sun was extremely well defined."

When the planet was about to leave the Sun similar appearances were presented.

> "The planet was as black as ink, and the body truly circular just before the beginning of egress, yet it was no sooner in contact with the edge of the Sun's disc, than it assumed

the same figure as before, the other part of Venus keeping well defined and truly circular."

No wonder the observations of the transit of 1761, affected as they were by peculiarities of appearance resulting from these various causes, for which observers were not on that occasion prepared, led to no trustworthy results.

Possibly the most trying experience befell the astronomer Le Gentil, who set forth for Pondicherry on March 26, 1760, nearly a year before the transit. Had he reached that station, he would have witnessed the curious spectacle of a transit, the middle of which occurred with the Sun almost vertically overhead. Unfortunately for Le Gentil, when he arrived at the Isle of France (on July 10, 1760) he learned that a war had broken out between France and England and that it would be unwise to proceed to Pondicherry, so he resolved to go to the island of Rodriguze instead. Then hearing that a French frigate was about to sail for the coast of Coromandel, he desired to avail himself of the opportunity to reach the point chosen by the expedition sent out by the French Academy. However, one delay after another

occurred, and it was not until the middle of March that he sailed again from Mauritius. There was not much time to be lost, for the transit was due on June 6, and sailing vessels could not be depended upon for rapid transit.

Detained by frequent calms, he did not reach the coast of Malabar till May 24, but there still might have been time enough to prepare for the observation had not the commander of the frigate learned that the English had taken possession of Mahe and Pondicherry. His only chance to escape capture was to make off as quickly as possible, the commander steering a course for Mauritius again, to Le Gentil's utmost despair. The 6th of June arrived, the sky was clear of clouds, but from the unsteady deck of the vessel Le Gentil made observations of little value to science.

As Dubois well remarks:

> "Le Gentil had experienced one of those mishaps which assume to the man of science all the proportions of a real misfortune; to have traversed so large a portion of the globe, to have endured all the weariness, all the privations, all the perils, of a long sea voyage, and to effect nothing, this was enough to have

disgusted anyone with scientific observation, or, at least, with Halley's method."

But Le Gentil was not discouraged, and no sooner returned to Mauritius than he set out again for Pondicherry, determined to wait there, for eight years, till the next transit of Venus. This occurred on June 3, 1769. The morning was fine, the sky cloudless, and the prospects most promising. Nevertheless, as the critical moment approached, a cloud hid the Sun from view, a torrent of rain fell, and the fruit of eight years' patient waiting was lost. Le Gentil had employed his spare time in studying the astronomy of the Brahmins, and all that was left to the unhappy astronomer was to return to France and publish a book on the astronomy of the Brahmins!

The results of the observations of the transit of 1761, were by no means satisfactory, so far as the determination of the Sun's distance was concerned. Some estimates made the distance nearly 100 millions of miles, while, according to others, the distance fell short of 80 millions of miles. The general impression among the astronomers would seem to have been that too much reliance had been placed on Delisle's method. Several

years later Cassini wrote as follows, regarding the arrangements for the transit of 1769:

> "Experience is our chief instructor; the fruit of her lessons repays us for the years passed in learning them. In 1761, the principal object had been missed for want of observations in places where the durations differed sufficiently. It was essential not to experience a second time the same disadvantage."

CHAPTER III

TRANSIT OF VENUS EXPEDITIONS

FOR the transit of Venus, due June 3, 1769, large and well equipped expeditions were sent to Mexico, Lapland, Kamchatka, Hudson's Bay, the South Seas, and other places where the whole transit could be observed. England took an important part in these arrangements, and the Royal Society presented a memorial early in 1768, to His Majesty King George III, requesting among other things, that a vessel might be fitted out at the expense of the Government "to convey proper persons to observe the transit, either from the Marquesas, or from one of those islands to which Tasman had given the several appellations of Amsterdam, Rotterdam, and Middleburgh," now known as the Friendly Isles.

After much debate, Lieutenant Cook (afterwards Captain, and world renowned) was eventually appointed. The *Endeavour*, a barque of 370 tons, originally built for the coal trade, was selected as a suitable vessel, and at the suggestion

of Captain Wallis, who had just returned from a voyage round the world, Otaheite (then called King George's Island) was chosen as the most convenient spot for observing the transit. The observers selected were Mr. Charles Green, assistant of Dr. Bradley, the Astronomer Royal, and Mr. Joseph Banks (afterwards the president of the Royal Society). Two draughtsmen, a secretary, and four subordinate assistants were appointed to accompany the observers. Though the main object of this expedition was to make careful observation of the transit of Venus, yet it included the Swedish naturalist, Solander, whose botanical observations in southern climes were among the most important results obtained on this occasion. All the arrangements in connection with the transit program were in charge of Mr. Joseph Banks and Mr. Green.

As soon as the *Endeavour* was completely fitted out for the long sea voyage to Otaheite, Captain Cook made sail from Deptford, on July 30, 1768. He anchored at Plymouth Sound on August 3, sailing thence after a brief delay in the direction of Madeira, where he arrived on September 13. Two weeks later he came in sight of the peak of Teneriffe, passing onward to Rio de Janeiro, where he was obliged to put in for necessary supplies.

Then leaving this port, he made his way to Port Royal Harbour, in the island of Otaheite, where he arrived after many vicissitudes, both on land and on sea, on the morning of April 13, anchoring within half a mile of the shore. Here he was welcomed by a great number of natives, who came out in canoes and bartered their goods for beads and other trinkets.

Owing to hints which Captain Cook had received from the Royal Society, he sent out two parties to investigate different spots which might prove of value in case Otaheite failed to meet the necessary requirements. On Thursday, June 1 (the next Saturday being the day of the transit) they went to a place called Elmayo, and finding a suitable site for their observations, they set up their instruments and made all the necessary preparations for the coming event. Despite the utmost care, however, during the course of the transit, the observers were unable to determine the exact instant at which Venus appeared in contact with the edge of the Sun's disc. Instead of a perfectly clear-cut view of this contact, the atmosphere round the planet, made the outline appear hazy and indistinct, leaving it uncertain, within a large number of seconds, at what instant the critical phase took place.

The following extract is taken from Captain Cook's *Journal*, Admiralty Records:

> "The day proved as favourable to our purpose as we could wish, not a cloud was to be seen the whole day, and the air was perfectly clear so that we had every advantage in observing the whole of the passage of the planet Venus over the Sun's disc. We very distinctly saw an atmosphere or dusky shade, round the body of the planet, which very much disturbed the times of the contact, particularly the two internal ones. It was nearly calm the whole day, and the thermometer exposed to the Sun about the middle of the day, rose to a degree of heat we have not before met with."

To give an idea of the discrepancy in the observations made of the transit, Green at Otaheite, found a difference of 40 seconds at ingress and 48 seconds at egress. Cook, at the same station, found the difference 60 seconds at ingress and 32 seconds at egress. Yet these two observers used two similar telescopes, magnifying 140 times. Maskelyne, at Greenwich, using a telescope magnifying 140 times, found the difference 52 sec-

onds; while Horsley, at the same station, with an achromatic telescope ten feet in length, magnifying 50 times, found the difference to be 63 seconds. Although the observations made in 1769, were on the whole much more satisfactory than those made in 1761, yet there was much to throw doubt on any determination of the Sun's distance based even on the later transit.

Over a century elapsed before another transit of Venus was due, and meanwhile new methods had been introduced, notably the photographic method. It is easy to see that by continuing during the transit, to take photographs of the Sun at two stations, in which Venus would be represented as a black spot on the Sun, these photographs combined would serve to indicate definitely the apparent path of Venus as seen at each of two stations suitably chosen. This method was looked forward to with much interest in connection with the transits of Venus in 1874 and 1882, because it was the first time that photography had been extensively employed in combination with delicate astronomical instruments.

Photographic pictures of the Sun were taken daily at Kew for many years beforehand, and it was found that an extremely accurate measure of the Sun's diameter could thus be made. If the

lens of a common telescope were used to produce an image of the Sun upon the sensitive plate the picture would be too small for accurate measurement. Therefore, an instrument termed a photoheliograph was devised to give an enlarged picture upon the sensitive plates. Mr. Dallmeyer, under the superintendence of Mr. De la Rue, constructed photoheliographs for the English and Russian expeditions.

> "In these instruments the image of the Sun produced in the focus of an ordinary telescope is enlarged by a special arrangement so as to give a picture of the Sun about four inches in diameter. This instrument based upon the principle of the Kew photoheliograph, is very perfect in its results, and convenient in actual practice. It is mounted equatorially so as to follow the Sun. The sensitive plate, which is prepared in an adjoining room, can be readily inserted and exposed. The intensity of direct solar light is so great that special means are necessary to give a short enough exposure. Before a photograph is taken, a sliding shutter in the interior of the instrument cuts off all light from the sensitive plate. This shutter is held

in place by a cotton thread. So soon as this thread is cut, a strong spring draws down the shutter, in which is a slit one-fortieth of an inch wide. The time taken by this slit to pass over any part of the Sun's image is the whole interval required for an exposure." *

This photographic process was employed at the transit of Venus which occurred on December 6, 1882, and from among the photographs taken at the critical moment one was selected which appeared to be that on which internal contact was most exactly represented. Nevertheless, there was much uncertainty about the matter, owing to the slowness of motion. It was like trying to tell the time accurately by means of a watch when you have only a minute hand and the hour hand is lacking, or *vice versa*. Another method for obtaining a large picture of the Sun was devised by Mr. Rutherford of New York, and adopted by Lord Lindsay in his observations at Mauritius. Nevertheless, the photographic observations resulted in failure, at least so far as the British stations were concerned. The pictures taken in 1874 and 1882 of the transits of Venus had not the

*_The Transit of Venus_, pp. 32-33. Professor George Forbes.

sharpness necessary for the delicate measurement to which they were subjected later on.

Stupendous efforts were made, in both 1874 and 1882, to deal with the problem of measuring the Sun's distance by means of observations of Venus while in transit across the face of the Sun. Large and well-equipped expeditions were sent to Siberia, Japan, China, Crozet's Island in the South Indian Ocean, Kerguelen's Island in the Antarctic Ocean, Hobart Town, Tasmania, Christchurch, New Zealand, and Chatham Island, South Pacific. Russian, French, Italian, Spanish, and Dutch astronomers all joined forces, and the whole organization was entrusted to a commission, of which the secretary was Professor Simon Newcomb (U.S.A.), who took so much trouble to ensure success for the undertaking.

In 1871, men of science were anxiously looking forward to the transit of Venus due in 1874, and again in 1882. Heated controversies arose with regard to the use of Halley's, Delisle's or other methods, an account of which is given in my father's book, *Transits of Venus*, and briefly summarised in other books, notably his *Old and New Astronomy* (see page 268). My father gained his point in essentials and saved the taxpayers to some extent in connection with costly expeditions,

which if carried out would have proved of no avail. Many of his suggestions were quietly adopted, though without due acknowledgment. Nevertheless, as Mr. Hinks remarks in his book on *Astronomy* (see pp. 143-144),

> "Unhappily, one must admit that the money spent on sending expeditions to Siberia, to the Pacific, to Kerguelen's Island in the Antarctic Ocean, was practically thrown away, through no fault of the astronomers, unless indeed they can be blamed for failure to foresee the difficulty which wrecked the whole enterprise. They had gone to determine the exact instant at which Venus appeared in contact with the edge of the Sun's disc. They expected to have a perfectly clear-cut view of this contact, and they did not at all anticipate what actually happened, that the atmosphere round the planet, filled with sunlight, blurred the sharpness of the phenomenon and left it uncertain within a large number of seconds at what instant the critical phase took place."

CHAPTER IV

SIR DAVID GILL'S WORK AT ASCENSION

AS SOON as it was definitely recognised that Venus when in transit across the face of the Sun was unreliable as a guide in determining its distance from our planet, the services of Mars and some of the minor planets were commandeered with far more satisfactory results. It happened that a favourable opposition of Mars was due in 1877, when the planet would be at its nearest to the Earth (a distance not exceeding 35,000,000 miles) and would be visible from after sunset till before sunrise. The advantages were obvious, for during this time owing to the rotation of the Earth the planet is apparently carried some seven thousand miles, showing a displacement among the stars of about forty seconds of arc in consequence.

The apparent movements of Mars as combined with the actual movements of the Earth are easily disentangled by the astronomer. As Mars approaches the Earth at such times by an amount not

much more than one-third the distance of the Earth from the Sun, it furnishes an excellent opportunity for measuring the Sun's distance, thus providing another method for the solution of this problem. At any rate, Sir David Gill, who had met with little success as a result of his observations of the transit of Venus in 1874 from a station at Mauritius, and had made up his mind that very little good would come of the transit expeditions of 1882, resolved to put planet Mars on trial as a possible factor in solving the problem. Lord Lindsay's heliometer, which had failed so signally through no fault of its own when in use at Mauritius during the transit of 1874, was again requisitioned by Sir David Gill, who purposed setting it up on the island of Ascension near the equator. The heliometer, the keystone on which the whole structure of the work rested, had never been used in so low an altitude as Ascension. Consequently it was deemed necessary to test it carefully beforehand, in order to ascertain whether it could perform the task imposed on it under the new conditions. Considerable interest was shown in the instrument by the members of the Royal Astronomical Society, and arrangements were made for its erection in the R.A.S. meeting room at Burling-

ton House, where the necessary trials could be made.

The heliometer was duly erected, and all had been brought nearly into the same condition of affairs as would be required at Ascension. Sir David Gill was applying a level to an inclined piece of wood cut to the angle of the latitude of Ascension, and was directing the workmen to give a final motion to the screw by which the inclination of the axis is changed, when the screw gave out. The overhanging weight of the heliometer and its counterpoises tore the lower ends of the cradle from his hand and, tilting upwards the polar axis, counterpoise weights, and heliometer tube, weighing in all several hundredweights, came down with a crash from a height of seven or eight feet to the floor.

One can imagine the consternation of Sir David Gill when he saw the heliometer on which he had built all his hopes lying apparently a wreck on the floor. The eye end was driven through the floor and slowly torn off, as the whole mass gradually turned round, smashing and crushing the more delicate rods, handles, and other attachments to the tube, and finally flattening out one of the copper cups which protect the ends of the slides from dust. The catastrophe occurred within

ten days of the time when the instrument was to be packed for shipment, and the case looked hopeless. However, on examination it was found that matters were not so desperate as they had appeared at first sight. The object-glass, scales, and all the main parts of the heliometer were intact, and the shattered portions were placed under the care of able mechanics who in six days made them whole as before. The cause of the downfall was due to the elevating screw being too short, a deficiency which could not have been anticipated, since the instrument was what is termed a Universal Equatorial, and therefore adapted to all latitudes. Had the accident occurred at Ascension, where there were absolutely no facilities for repairing the instrument, the result would have meant the utter failure of the expedition. However, under the care of skilful mechanics, the damage was soon repaired and in six days the instrument was whole as before.

On June 14, Sir David Gill, accompanied by Lady Gill, sailed from Dartmouth, reaching St. Helena in July, where they landed, making a brief stay during which they explored the island, taking far more interest in the remains of Halley's Observatory than in Napoleon's tomb. (The Observatory was erected in the seventeenth century

when Halley commanded the first scientific expedition for astronomy and terrestrial magnetism in southern latitudes.) On July 10 they embarked on the S. S. *Edinburgh Castle* for Ascension Island, where they landed on July 13. The difficulties encountered on this inhospitable volcanic "clinker," which Lady Gill compared to the "Abomination of Desolation," have been most graphically described by her in that charmingly written but little known book entitled *Six Months in Ascension.* To quote her own words:

> "A few scattered buildings lay among reddish-brown cinders near the shore—a sugar-loaf hill of the same colour rose up behind and bounded the view. We looked about in a sort of helpless way for 'Green Mountain,' but it was nowhere to be seen, and we set it down as a fable—a mere myth. 'Nothing green,' we said, 'exists, or could exist here.' Stones, stones, everywhere stones, that had been tried in the fire and are now heaped about in dire confusion, or beaten into dust which we see dancing in pillars before the wind. Dust, sunshine, cinders, and low yellow houses frizzling in it all. Is that Ascension?"

Yet such, indeed, was the dreary desolate spot where Sir David Gill and his brave cheerful assistant, as Lady Gill termed herself, struggled amid adverse conditions of many kinds during a period of six months. Captain Philimore, according to the account given by George Forbes in his life of David Gill, was very helpful, and "established them in an empty cottage." Can anyone imagine anything more dreary, yet Lady Gill tells us how she explored every nook of her little home before attempting to fit herself therein. She gloried over the bare walls, bare floors, and bare tables, till she was disturbed in the delightful occupation of mentally putting her house in order by the cook, who came to remind her that the larder was bare, too. Nevertheless, in a few days she succeeded in making this empty house homelike, and meanwhile Sir David Gill had set up the instruments without mishap. We are told that the observing books were laid out, but they remained blank for weeks. Mars was obscured by clouds every night, and the case seemed hopeless, until it occurred to Sir David Gill that the clouds might be local, due to the vapour-laden trade wind passing over the hilltop to the south-east. So one night while he remained with his instruments, his wife insisted on marching with

two guides and a lantern over the pathless rock for some miles while husband and wife made simultaneous notes on the weather every half hour from 10 P. M. to 3 A. M.

Hill, the cook, was called upon to act as escort on this occasion, carrying rugs and a luncheon basket, and Corporal B., who knew something of the way, though possibly not more so than Lady Gill. When she offered herself as pioneer, she tells us her offer was at first rejected with some decision: "Impossible! You have never been beyond Garrison; there is no road; there may be dangerous gullies; and wild cats infest the plains —you would find the walking bad enough by day, and at night—*impossible*."

"But having," as Lady Gill tells us, "a considerable leaven of Luckie Mucklebackit's spirit in me, I meant to try hard for my own way; and after showing how carefully I had been studying the Admiralty Chart—studying it till every crater and every watercourse seemed stamped upon my brain, the 'impossibles' grew fainter till finally they disappeared. The chart was brought out, *not* for the first time, and I was proud to show off my knowledge."

Then, accompanied by the two escorts already mentioned, and provided with a watch carefully

timed with the chronometers, Lady Gill started on her way at ten o'clock. "My spirits were higher," she tells us, "than they had been for many nights, but David looked anxious and warned me again and again not to run into any danger. I reassured him with boasts of my knowledge of the chart and of all the places of the stars. Besides, in an hour the moon ought to rise, and in the tropics she is a brilliant lamp; but in case of the clouds thickening we provided ourselves with a lantern and a bull's-eye to serve in her stead."

Then follows the description of that arduous walk on a road "soft and yielding, and bestrewn with loose lumps of clinkers; moreover I had made the mistake of putting on low shoes." Nevertheless, bravely she trudged along with her guides till midnight, when she tells us she spread her rug on the clinker, and tried, by looking hard, to make "the darkness visible." Mars had risen about 30 degrees and just skirted a dark cloud which covered the north and northeast, leaving the other parts of the sky brilliantly bright. As Sir David Gill had surmised, the dark clouds which had so interfered with his observations proved to be merely local, for as Lady Gill advanced on her way she became convinced that her husband was right. "Before starting on our return jour-

ney," to quote Lady Gill, "I got the men to make a cairn of clinker, which we topped by a bottle with a bit of red cotton tied to it, so that David might see where we had stopped, should he decide to come and explore for himself."

This he did when he heard her favourable report, for when he compared notes there could be no doubt the clouds were local, and the instruments must be packed up again and transported to the windward side of the island. On August 1, the dismantling process began, and the next day a steam launch towed their gear in lighters to the cove, which had been christened "Mars Bay," and foundations for the new observatory were laid on the bleak, dusty, volcanic stones. After overcoming numerous difficulties, a splendid set of morning and evening observations of Mars were secured, enough to ensure the success of the expedition, and a triangulation was then made by heliometer of all the comparison stars. The actual opposition of Mars occurred on September 5, 1877, and Lady Gill describes in her diary the intolerable anxiety on that eventful occasion when she saw heavy clouds forming in the sky, but at last she saw "Mars shining steadily in the pure blue horizon beneath." On this, the night of opposition, the planet would be in the most favour-

able position for beginning observations about 2.30, but at 12.50 a rising cloud gave cause for alarm should it spoil the chance of securing observations of Mars.

"How my heart beat," writes Lady Gill, "for I saw the cloud rise and swell, and yet no silver lining below. I dared not go inside the Observatory, lest my uncontrollable fidgets might worry the observer, but sat without on a heap of clinkers and kept an eye on the enemy. Five, ten, fifteen minutes! Then David called out, 'Half set finished—splendid definition—go to bed!' Just in time, I thought, and crept off to my tent, thankful for little and not expecting more, for one arm of the black cloud was already grasping Mars.

"My husband would, of course, remain in the Observatory for the rest of the night to watch for clear intervals, while I was expected to go to sleep. But how could I? I took up a book and tried to read by the light of a lantern for a few minutes; then I thought to myself, 'Just a peep to see whether the cloud promises to clear off.' I looked forth, and, lo! no cloud! I rubbed my eyes,

thinking I must be dreaming, and pulled out my watch to make sure I had not been asleep, so sudden was the change. No! truly the obnoxious cloud had mysteriously vanished, and the whole moonless heavens were of that inky blackness so dear to astronomers. Mars now outrivalled Jupiter in ruddy splendour; Orion had flung abroad his jewels like hoar-frost; the Pleiades glittered in such bewildering multitude that it seemed as if the lost Pleiad had returned with a train of shining followers from some other system.

"While my eyes drank in this beautiful scene, my ears were filled with sweet sounds issuing from the Observatory. 'A. seventy and one, point two seven one; B. seventy-seven, one, point three six eight,' etc. Let not anyone smile that I call these sweet sounds. Sweet they were indeed to me, for they told of success after bitter disappointment; of cherished hopes realised; of care and anxiety passing away. They told, too, of honest work honestly done—of work that would live and tell its tale when we and the instruments were no more.

"Happier hours I never spent than those early morning ones under this beautiful

heaven; for in helpless restlessness I had again taken up my position on the clinker. The night was unusually still, and outside the Observatory there was not a sound save the gentle flapping of tents—like the wings of passing birds; and the continued murmur of greeting from the waves as they met the shore. Time passed unconsciously, for I was giving my imagination full play, and when I heard the Observatory dome shut, I could hardly believe that I had been dreaming on a rock for three hours. The awakening was as pleasant as the dream had been. David was radiant, and no wonder. All our previous disappointment, fatigue, and anxiety were forgotten in the good fortune of to-night, and now we might rest."

When the mail boat arrived on January 24, in England the news of Sir David Gill's successful observations was greeted by astronomers with the greatest enthusiasm. The Gold Medal of the Royal Astronomical Society was awarded to him in 1882, for this work on the Solar Parallax, and in the same year he was awarded the Valz Medal of the French Academy of Sciences. It

must not be forgotten how much of the credit was due to his wife who so bravely helped him through her sympathy and readiness to respond when she could be of assistance. As Sir George Airy said at one of the meetings of the R.A.S. held during the year 1878:

> "A considerable and highly appreciative part of the success of the expedition was due to the unfatigued assistance you obtained from Mrs. Gill, and I cannot but ask her most sincerely to accept, from my part too, warm thanks of a scientific colleague for the enduring and successful share she has taken in such an important astronomical work."

Two years were spent in the reduction of the observations, producing the result of 92,080,000 miles for the mean distance of the Sun. Then, as so often happens in scientific enterprises, it was found that the red colour of the planet had produced a systematic error in the observations. As Sir David Gill remarked during the course of an address given by him on July 30, 1880, at the annual meeting of the South African Philosophical Society:

"Mars is a very difficult object to observe, very brilliant, and very large he looks in the telescope, and his limbs or edges are fringed by coloured light when he is observed at a low altitude, because the Earth's atmosphere acts like a prism colouring his lower limb red, and his upper limb violet. Now red is a much more staring or well-marked colour than violet, especially when viewed in the field of view of a telescope, illuminated by white light, for it is necessary to illuminate the field of view of a telescope in order to view the spider webs with which the observations are made, and thus the observer has a tendency to cut with his spider web more deeply into the feeble violet limb than into the more glowing red limb. The effect of his so doing is to make the distance, which results from the observations, smaller than the truth."

The next step was to try again, and three minor planets, named, respectively, Victoria, Iris, and Sappho, were subjected to the keenest scrutiny at their oppositions in 1888 and 1889 for the purpose of solving the solar parallax problem. Sir David Gill, who had been appointed Her Majesty's As-

tronomer at the Cape, reorganized the work, and the results eventually filled two red volumes of *Annals* of the Cape Observatory. However, the matter was not allowed to rest there, for in 1898 a small insignificant-looking minor planet was discovered on a photographic plate taken by Dr. Witt at the Urania Observatory, Berlin, which revived interest, and a final attempt was made to discover the distance of the Sun therewith.

The name of Eros was given to the planet, and despite the fact that it was only twenty miles in diameter (comparable in size with the Isle of Wight), yet it comes at times within a distance of 14 million miles from the Earth, and is therefore admirably adapted for observation for the determination of the distance of the Sun. Unfortunately, these near approaches are rare, one occurring in 1894, before the planet had been discovered. There was a fairly close approach in 1901, when photographs were taken at all the leading observatories.

In his book on *Astronomy*, Mr. Arthur R. Hinks, at present the Gresham Lecturer on Astronomy, but at that time chief assistant at Cambridge University, gives a detailed account of the work undertaken on this occasion. He tells us that the skies of that winter were very unfavour-

able. At Cambridge he was on duty with the photographic telescope from dusk till dawn for nearly three months, during which time only five or six nights were more or less clear throughout. To quote his own words:

> "Had visual observations alone been possible, one could scarcely, in those brief and broken intervals of clear sky, have obtained a sufficiency of measures. But the photographic plate, in work of this kind, is so much more expeditious, that it was possible to obtain at Cambridge alone about five hundred photographs on which the position of the planet among the stars could be measured with great precision. Many other observatories obtained as much material; a few, happily situated in fine climates, obtained much more; while the visual observers had been equally active and had accumulated an enormous mass of measures, referring the planet to great numbers of faint stars whose positions at the time were entirely unknown. Here, then, was an overwhelming richness of raw material for the solution of the problem."

Another difficulty also encountered was that of bringing the material together into systematic form. Mr. Hinks had discovered appropriate methods of dealing with the problem, and to him was entrusted the pleasant though arduous task of making the necessary calculations based on the material furnished. As Mr. Hinks remarks in his book, "Some one has laid down the principle that it is a mistake to plan work which will take longer than ten years to complete. Judged by their standard, the solar parallax determination from the planet Eros just escapes censure. It was begun in the Paris Congress of 1900, and it was practically finished when the final results were communicated in brief to the Académie des Sciences in 1910. . . ." The result which emerges from a very big enterprise such as the Eros campaign may be expressed in four figures, which are usually written thus:

Solar Parallax from Eros = 8″.806.

We find from the above value for the solar parallax that the mean distance of the Sun from the Earth is 149,400,000 kilometres, or 92,830,000 miles.

The method used on this occasion consisted in comparing photographs taken at the same time

at distant observatories. Owing to the changed point of view, Eros appears in a slightly different position among the stars with which it is compared, as shown on the two plates. This shift of position gives a measure of its distance, and the near approach of Eros makes the little planet a valuable stepping stone in the determination of solar parallax. The next near approach of Eros will be in 1931, when the amount of uncertainty regarding the Sun's distance will probably be reduced still further.

Having determined the mean distance of the Sun from the Earth, it is a simple matter to determine the size of the Sun. It is only necessary to measure its mean apparent diameter. This is found to be 32′. 04″. Expressing this in circular measure, and multiplying by the Earth's distance, we find that the Sun's diameter is about 865,000 miles, or about 109 times that of the Earth. If a tunnel could be made through the centre of the Sun, eight thousand miles high and equally wide, then there would be room enough and to spare for 109 globes the size of our planet placed side by side. If a railroad track were laid down in the tunnel, a train going at the rate of sixty miles an hour would require 600 days, or more than a year and a half, in traversing the distance from entrance

to exit. Should the track be arranged for a circular tour around the Sun, the train would be five years on its way before it returned to the starting point.

The volume of the Sun exceeds that of the earth 1,300,000 times, and its mass 32,000 times. Naturally, the force of gravity is considerably greater at the Sun's surface under these conditions, than it is on the surface of the Earth. If we calculate the force of gravity at the Sun's surface by dividing its mass by the square of 109, the number of times the diameter of the sun exceeds that of the Earth, we find it to be 27 times as great as on the Earth. For instance, a man who weighs 140 lbs. here would weigh nearly two tons, and should he fall down he would require the assistance of a derrick to haul him to his feet again. Even if the footing were good, he would be unable to stir, and a game of football under such conditions would be an impossibility.

CHAPTER V

THE SUN, DISPENSER OF LIGHT AND HEAT

THAT the Sun is the dispenser of light and heat was recognised long ago by the early watchers of the sky, as we have already seen, but the revelations of modern science have shown us that the Sun is not only aglow with intense light and heat, but is in a state of fierce turmoil. Vast oceans of molten metal as deep as the Atlantic is broad are stirred to their very depths by tumultuous storms. The atmosphere hovering over these regions is composed of fiery vapours so intensely hot that they shine with their own inherent lustre. Tremendous forces are at work, causing vast upheavals of metallic vapours from which glowing atoms are expelled with stupendous velocity, falling backward in a shower of fiery rain.

Such are some of the marvellous processes taking place on the Sun, which can be observed visually by means of the spectrohelioscope recently designed by Dr. George E. Hale, Honorary Director of the Mount Wilson Observatory, Califor-

nia. One can actually see the motion of flames of fiery hydrogen, probably ascending to a height of thousands of miles above the surface of the Sun, so that it literally presents the appearance of a prairie fire. Yet owing to the vast distance separating us from the Sun, all seems peaceful and quiet on its surface. In reality an uproar and tumult prevails thereon, compared with which the roar of the hurricane, the crash of the thunderbolt, the hideous groaning of the earthquake would seem but the faintest whisper. Fortunately for us, as regards its light and heat, we are nestling comparatively closely within the sheltering rays of the Sun. Our very existence depends upon the lavish supply of light and heat it is pouring continuously upon our planet. Although it no longer occupies the important position it once did, when it was raised to the rank of a god, yet science reveals its absolute supremacy in the scheme of life, as far as we are concerned. Were the light of the Sun extinguished and its supply of heat withdrawn, life would cease on our planet, which would become a derelict in space drifting in its ever-ceaseless round—a dead world. Fortunately for us, the furnace whose fires maintain the life of the Sun ensure warmth and comfort for its circling planets.

MOUNT WILSON OBSERVATORY
The 150-foot tower telescope from the Northeast

The Sun is surrounded by an atmosphere composed mainly of hydrogen and calcium clouds which tone down, as it were, the brilliant glare of sunlight which would otherwise overwhelm us with its splendour. If this atmosphere were removed, the surface of the Sun would be slightly changed in colour. The blue and violet rays now largely absorbed would reach us in their due proportion, and would make the Sun appear of a bluish-indigo tint. However, the alteration of tint would be very slight. What we actually see when studying photographs of the Sun is the darkening at the edge shading off from the brightness at the middle of the Sun's disc, where the absolute lustre is 150 times as great as that of calcium light. It far surpasses the brilliancy of the glowing carbon of the electric light, when the intensity of the limelight and that of the electric light, respectively, are at their greatest. One can also compare sunlight with the light of a standard candle. When the Sun is in the zenith, it illuminates a white surface 60,000 times as strongly as a standard candle at a distance of one metre. When the Sun's light is compared with that of the full Moon, we find that it exceeds it about 600,000 times.

An interesting experiment was made in 1878

by the late Professor S. P. Langley (at the time Director of the Allegheny Observatory, U.S.A.) by means of which he was able to compare the light of the Sun with the brilliant surface of the molten metal in a Bessemer "converter." This is an enormous iron pot lined with fire-brick and capable of holding thirty or forty thousand pounds of melted metal. It is swung on trunnions, so that it can be raised by an engine to a vertical position or lowered by machinery so as to pour its contents out into a cauldron. Imagine fifteen thousand pounds of fluid iron streaming down into the mouth of the converter from an adjacent furnace where it has been melted.

> "Then the engine lifts the converter into an erect position, while an air-blast from a blowing-engine is forced in at the bottom and through the liquid iron, which has combined with it nearly half a ton of silicon and carbon—materials which, with the oxygen of the blast, create a heat which leaves that of the already molten iron far behind. After some time the converter is tipped forward, and fifteen hundred pounds more of melted iron is added to that already in the pot.

> What the temperature of this last is, may be judged from the fact that though melted iron is dazzlingly bright, the melted metal in the converter is so much brighter still, that the entering stream is dark brown by comparison, presenting a contrast like that of chocolate poured into a white cup." *

To compare this dazzling brilliancy with that of the Sun, Professor Langley had placed his apparatus, consisting of a long photometer-box with a *porte-lumière* attached to one end, in an open window at a point where its view could be directed down into the converter on one side, and up at the Sun on the other. The mirror forming the most important part of this apparatus reflected the Sun's rays through the box, and then on to the pouring metal, tracing their way to it by a beam visible in the dusty air. A measuring apparatus was placed in the path of the beam, taking a sample of the Sun's surface of equal size with the fluid metal, bringing them face to face, as it were, to see which was the brightest. The light from the Sun proved to be over five thousand times that from the molten steel, though the latter, separately considered, seemed to be itself,

**The New Astronomy*, pp. 106-107. S. P. Langley.

as Professor Langley stated, of quite sunlike brilliancy.

Professor Langley found that the best point of observation was in the line of the blast and a shower of sparks consisting of little particles of molten steel. These were driven over the instrument and the observer at every "pour," so that his position was not an enviable one. The rain of wet soot from chimneys without, the bombardment from within, and the moving masses of red-hot iron around made the experiment somewhat trying.

We must not conclude from this that the temperature of the Sun is five thousand times that of steel, but it is probable from the latest estimates that the effective temperature of the Sun is about 5,800° centigrade. (This is the average temperature of its radiating surface, the temperature which a sheet of lampblack must have in order to radiate the amount of heat actually thrown off by the sun. Physicists have taken the radiating power of black as *unity*.)

Every square centimetre of the Sun's surface is continuously radiating energy at the rate of a 9 H. P. engine, and practical men are turning their attention to this as a source of power. Dur-

ing the eighteenth century a large burning lens was constructed in France. All the heat falling on the great lens was concentrated on a smaller one, and the smaller one concentrated it in turn, till at the very focus we are assured that iron, gold, and other metals ran like butter. In England, the largest burning-lens on record was made about the same time, by an optician named Parker, for the English Government, who designed it as a present to be taken by Lord Macartney's embassy to the Emperor of China. The lens was three feet in diameter and very massive, being seven inches thick at the centre. In its focus the most refractory substances were fused, and even the diamond was reduced to vapour.

> "Unfortunately, when the Emperor of China received the lens, fearing it might be harmful to him in some mysterious way, he ordered a smith to test it by striking it with his hammer. When the hammer rebounded from the solid glass, this seemed to prove that there was magic in the thing, and it was immediately buried, and is still reposing under the soil of the Celestial Flowery Kingdom." *

**The New Astronomy*, pp. 103-104. S. P. Langley.

Experiments with burning mirrors for the purpose of utilizing the Sun's heat have been made since the days of the renowned philosopher Archimedes. In the year 214 B.C. he is said to have set the ships of the Roman fleet on fire by concentrating the Sun's rays upon the ships by means of mirrors erected on the shore. Whatever may be the truth of this story, its possibility has been proved beyond a doubt by the experiments of the French naturalist Buffon in 1747. Mounting 360 plane mirrors, each 16 by 22 centimetres, on a frame in such a manner that each could be adjusted separately, so that their reflected rays would be concentrated to a focus at any desired distance, he found it possible to set fire to wood at 68 metres. With 45 mirrors he melted 3 kilograms of tin at 6.5 metres, and with 117 mirrors, it is said, he was enabled to melt silver at the same distance.

A very simple experiment illustrates the principle used by Archimedes and Buffon, such as turning a magnifying glass to the Sun on a fine sunny day and holding a piece of paper at the proper distance until a bright spot of light is obtained. Then a hole is burned in the paper at the point whereon the sunlight is concentrated. (It is possible to light a pipe in this way, though the writer cannot vouch from personal experience,

but has seen it done many a time.) Almost any kind of lens will serve the purpose, providing it is not too flat, as those in spectacles generally are. A small magnifying lens such as is used for reading small print can be made to collect the rays of sunlight until they are brought to a focus, so that their concentrated heat burns a hole in whatever happens to be in their path. Some ingenious person turned this principle to good account many years ago, in connection with the burning glass on old Brighton pier. It was so arranged that the spot of sunlight passed over the touch-hole of a small cannon at local apparent noon and fired it off. Burning glasses are also useful in enabling us to obtain an exact record of the hours of sunshine, though in this case the lens is replaced by a glass globe. As the Sun moves over the sky, the bright spot of light moves and burns its track on a sheet of paper marked with lines indicating the hours. Therefore, when the Sun is hidden by clouds, naturally the record ceases, and hence it is possible to know exactly the number of hours of sunshine each day, and *vice versa*.

Sir John Herschel made some entertaining experiments during his sojourn at the Cape of Good Hope, 1834-38, with what is termed the "hot-box" principle. When the heat from the Sun is

confined so that it cannot escape, and so forced to accumulate, very high temperatures are attained. Thus, in a small mahogany box blackened inside, covered with window glass fitted to size, but without putty, and simply exposed perpendicularly to the Sun's rays, an enclosed thermometer marked on November 21, 1837, 150 degrees. When sand was heaped round the box, to cut off the contact of the cold air, the temperature rose to 177 degrees. Some amusing experiments were made by cooking fruit, meat, eggs, all of which after a moderate length of exposure were found perfectly cooked—the eggs being rendered hard and powdery to the centre. On one occasion, a stew of meat and vegetables was prepared, and eaten with no small relish by the onlookers.

Herschel found from his experiments that about one-fourth of the Sun's light and heat is cut off at midday by the air, and taking this into account and making the requisite calculation for a large extent of surface, he found that the quantity of the Sun's heat that fell on an area of one square mile would be sufficient to melt in a single hour 25,000 tons of ice. Now that is merely the quantity received by a square mile of the Earth's surface. But the Earth presents to the Sun a sur-

face (regarding her for a moment as a flat disc) 50,000,000 square miles in extent. The Sun is continually radiating energy into space, and of this energy only a small part is intercepted by the Earth. The solar radiation expressed in terms of energy is nearly one hundred thousand horse power continually emitted from each square metre of the Sun's surface. Of all this heat the Earth receives but the two-thousand-millionth part, and the remainder is apparently squandered in space. It is as though a millionaire spent millions of pounds and dropped merely a penny each day in the bank, out of his vast income. In the same way only a fractional part of the Sun's heat appears to be applied to any useful purpose as far as our planet is concerned. Yet it is not for us to judge of the operations of nature, even when—as the saying is—"nature in filling a wineglass upsets a gallon."

Yet that is what the Sun appears to be doing, for in every second of time it gives out as much heat as would be emitted by burning millions of millions of tons of coal. To maintain such a development of heat by combusion would require the hourly burning of a layer of the best anthracite coal from nineteen to twenty-four feet thick over the entire surface of the Sun—that is, a ton

for every square foot—at least ten times as much as the consumption of the most powerful blast furnace in existence. At that rate, the Sun, if made of a mass of solid coal, would not last over five thousand years.

There must be some means by which the Sun is able to replenish its store of heat. According to some authorities it may be due to the downfall of meteors upon its surface, or the gradual contraction of the Sun under the influence of its own gravitation, but if this theory were correct we should be forced to the conclusion that the Earth would not receive sufficient heat to maintain life on its surface for many million years longer. The energy of the Sun may be due to radioactive processes, but Rutherford has shown "that if the Sun were made entirely of uranium, only about five million years would be added to its duration as a dispenser of heat."

Within the last twenty-five years attempts have been made to devise commercial economical means of employing the hot-box principle, already referred to, for power. When we consider the growing demand for such power in the world, where the coal supply is gradually lessening, and when it has gone there will be none wherewith to renew the supply, such attempts at utilising the Sun's

heat are of the utmost importance. "It seems highly probable," to quote remarks made by Dr. Charles G. Abbot, in his book on *The Sun*, and an expert with regard to utilising the energy of the Sun, "that solar cooking utensils with water heaters and heat reservoirs, and embodying the 'fireless cooker' principle, will come into extensive use. For it is not very hard to see that very inexpensive apparatus may be designed for combining these utilities, and that housekeepers will welcome a relief from hot conditions of summer." In fact, successful attempts in this direction were made in 1920, at the Smithsonian observing station, on Mount Wilson in Southern California.

Dr. Abbot tells us in his book on *The Earth and Stars*, that the whole cooking operation of a small family, including baking, boiling, stewing, and preserving, was done regularly with a solar cooker. A cylindrical mirror focussed the Sun's rays upon a blackened tube, parallel to the Earth's axis, and containing engine cylinder oil. A simple clockwork kept the mirror facing the Sun all day long. The oil becoming hot, expanded, and thus maintained a gravity circulation through a reservoir above the level of the mirror. Two ovens inserted in the reservoir were bathed by the hot oil and reached temperatures high enough to bake

bread. Being well protected from losses of heat, the ovens kept hot overnight, so that cooking could go on at any time despite occasional clouds. This device was interesting and worked well, Dr. Abbot tells us, "but was too expensive for general use without modifications," and he might have added that it is too unreliable, at any rate on Mount Wilson. (The same remark applies to the solar heaters used in connection with the water supply in use for the bungalows on Mount Wilson, as the writer knows from her own experience. On the occasion of her visit to Mount Wilson, during the month of March, 1926, after a week during which banks of clouds wreathed the mountain heights without a break, the water supply untouched by the Sun's rays was bitterly cold, and had we depended upon the solar heater for our cooking, we must have fared badly.)

According to Dr. Abbot, a well-known authority on the subject, two other types of solar engine deserve mention. First is the type developed by Mr. A. G. Eneas and used for a time to pump water at the South Pasadena Ostrich Farm. It consisted of a great conical mirror which concentrates the solar rays upon a tubular boiler which propels a steam engine. The instrument is moved by appropriate mechanism to face the Sun

all day. A second type is the Shuman-Boys installation of cylindrical mirrors, which the writer saw in Cranford, New Jersey, in 1910, and a heat absorber of the same kind was used at Meadi, near Cairo in Egypt just before the recent World War, for irrigation purposes. As the latitude of the place was small, the mirrors could be placed nearly horizontally. They were rotated so as to focus the Sun's rays upon a horizontal tubular boiler of rectangular section. Steam was thus raised to drive an engine. In both the Eneas and Shuman-Boys installations the boiler tube was protected by glass covers from loss of heat by air currents.

When less fortunate countries (as far as sunshine is concerned, as compared with Egypt or California) become bankrupt in coal, then by degrees there may be an exodus to those lands where the Sun dispenses its heat with lavish generosity. In Egypt, where the Sun shines with dazzling brilliancy all the year round, the land will become the most fertile in the world, capable of yielding heavy crops. Cultivation of the natural resources of lands where sunshine is at a premium will serve as a magnet, attracting not only those in search of wealth, but material comfort. According to Dr. Abbot, "It is well worth while to work earnestly towards the improvement of means

for utilising solar radiation for power purposes. There may be a great need for it sooner than expected." Solar energy can be conveyed by electric current to regions less favoured by sunshine. Probably this will be done when coal runs short.

CHAPTER VI

THE SURFACE AND SURROUNDINGS OF THE SUN

ABOUT one hundred and thirty years ago (1794), the renowned astronomer Sir William Herschel advanced the fascinating theory that the Sun was "a large and lucid planet, the only primary one of our system." He supposed that it was most probably inhabited like the rest of the planets, by beings whose organs were adapted to the peculiar conditions of that vast globe. According to his theory, the Sun was surrounded "by protective clouds, dense, opaque, and highly reflective, which must add a most capital support to the splendour of the Sun by throwing back so great a share of the brightness coming to them." The movements of the clouds indicated the action of terrific storms and fierce hurricanes. Through openings in the brilliant layers "ascended empyreal gas" which sometimes burst through the planetary regions of clouds and, ascending, "spread outward and mingled with other superior gases."

The solid globe, thus girt round with clouds and fire, was depicted as a highly eligible place for residence, possessing an equable climate, romantic scenery, luxuriant vegetation, and smiling landscapes. Herschel considered it might be admitted that the Sun "was richly stored with inhabitants," for the lucid shell visible from the exterior possessed according to his theory, none of the intense heat now attributed to it. Its blaze were merely a superficial display, and the luminous curtain of the planetary clouds was everywhere closely drawn round a world perfectly adapted to vital needs.

This idea was plausible and alluring, in the eighteenth century, and we even find it referred to in a book by E. H. Burritt, entitled *The Geography of the Heavens*, published fifty years later (1846) as one of the conflicting theories of the day.

> "The prevailing theory," it says, "seems to be that the lucid matter of the Sun is neither a liquid substance or an elastic fluid, but that it consists of luminous clouds floating in the Sun's atmosphere, which extends to a great distance, and that the dark spots are regions on the opaque body of the Sun

seen through the openings in his atmosphere. Herschel supposes that the density of the luminous clouds need not be greater than that of our Aurora Borealis, to produce the effects with which we are acquainted."

Philosophers of that period had a firm belief in the possibility of other worlds than ours, and when Herschel advanced his theory in the picturesque language above quoted, it appealed strongly to the imagination of readers thereof, until it was dislodged by the irresistible claims of spectrum analysis. A hint as to the actual facts concerning the constitution of the Sun was given by Sir Isaac Newton in 1675, when he made his memorable test regarding a beam of sunlight. He was experimenting one day in a very dark room with a glass prism which he had placed directly in the path of a beam of sunlight shining through a round hole in a shutter. The hole was one-third of an inch broad, and the sunlight passing through it and the prism was refracted upwards towards the opposite wall of the room, and there formed a rainbow-coloured image of the Sun. When the prism was removed a bright spot of the same shape as the hole in the

shutter through which the ray of sunlight was admitted was seen on the screen.

Now why was the light spread out into a rainbow-coloured band after it had passed through the prism? After much patient investigation Newton found the answer to his query. He discovered that though a beam of sunlight looks white, yet in reality it is composed of differently coloured lights blended together. The prism disentangles them like skeins of silk and spreads them out in a band varying from red to violet, in the order so aptly described by Thomson:

"First the flaming red
Sprang vivid forth, the tawny orange next,
And next delicious yellow, by whose side
Fell the kind beams of all-refreshing green:
Then the pure blue that swells autumnal skies,
Ethereal played, and then of sadder hue
Emerged the deeper indigo (as when
The heavy-skirted evening droops with frost),
While the last gleamings of refracted light
Died in the fainting violet away."

All these colours from "flaming red" to the "fainting violet" are contained in the white shaft of the sunbeam, wherein they remain hidden until they are trapped by a prism. It was Newton who

first drew attention to their presence when, as we have seen, his simple prism separated a ray of white light into its varied colours, leading eventually to the development of what is termed spectrum analysis. When a fine crevice or slit is used in a spectroscope for admitting a beam of light, numberless lines make their appearance. Thus, a spectroscope analyses the light of the Sun. The first to notice this interesting fact was Wollaston in 1802, and in 1814 Fraunhofer, a noted optician of Munich, mapped 576 lines which are called by his name, and the letters which he used to designate the more prominent lines are still retained. Not until nearly half a century later (1858) was the key to the meaning of these lines discovered by Kirchhoff, and what he said in substance was as follows: There is a solid or liquid something in the Sun giving a continuous spectrum, and around this are vapours of sodium, calcium, iron, copper, aluminum, barium, chromium, magnesium, nickel, cobalt; all these are existing in an atmosphere and are stopping out the Sun's light. If the Sun were not there, and if these things were observed in an incandescent state, we should get exactly these bright lines from them.

Thus, by matching the dark lines in the solar

spectrum and comparing them with the bright lines produced by the vapours of sodium, calcium, iron, etc., burning in the electric arc, we can determine the chemical constitution of the atmosphere which produces them. When the beam of sunlight passes through a narrow slit in the spectroscope before it reaches the prism, it undergoes a transformation the moment it passes that barrier, emerging in all the colours of the rainbow in the form of narrow and straight lines (images of the slit) lying side by side, so many and so close together that they seemingly merge into an almost continuous band. When the light is thus split up, spread out, and dispersed in orderly array, it is subjected to the keenest scrutiny. Its light is analysed, and compared with that produced by certain elements burning in the electric arc which at such times approach a temperature such as we find in the Sun. Thus, the picturesque abode described by Herschel crumbled in ruins beneath the searching test of spectrum analysis.

The central nucleus of the Sun, we now know, is mainly gaseous, this being indicated by its low mean density and its high temperature. Surrounding this nucleus is a shell of incandescent clouds formed by the condensation of the vapours which are exposed to space. As the intensely heated

vapours of the central nucleus make their way outward through openings in the clouds, they come in contact with the cooler layers of their own kind, and delaying to warm them up—as it were—they are left behind. Hence the blank at certain parts of the spectrum, showing the place where the missing elements are due. Though seemingly black, they are only so by contrast, just as in the case of the interior of a sun spot which in reality is as bright as limelight. However, when compared with the dazzling surface of the Sun, which is one hundred and fifty times brighter, the reason why sun spots appear dark is obvious. The same reasoning applies to the apparently dark lines in the spectrum, which can be proved as follows.

When a gas flame, or the limelight used for lantern observations, is observed with a spectroscope, an unbroken band of colour is seen. Now, if the beam of sunlight is made to pass through a sodium flame on its way to the prism, the position occupied by the sodium vapour in the spectrum will show two black lines upon the continuous spectrum. Turn off the incandescent light, and the sodium lines are seen bright and alone. The flame is not altered by the limelight passing through it, but the two sodium lines appear dark by contrast with the continuous spectrum. Place

a screen before the limelight, and once more the two yellow lines make their appearance; remove the screen and they appear dark; and so it is with all the dark lines in the solar spectrum, each line corresponding to a special element. If many such are burned in the flame of a Bunsen burner, each one selects its own space which it alone can occupy, just as, in the instance of sounding a note on the piano, each note has its own place in the octave. When all the notes are sounded we have the equivalent of the continuous spectrum, and the black lines are equivalent to certain notes not played, as in the case of a chord where these notes are missing.

Spectroscopic analysis forms the very basis of all our knowledge regarding solar physics, and we must thoroughly understand the method of its teaching and the extent to which it may be relied on, otherwise views on the subject will be vague and unsatisfactory. Extensive maps of the solar spectrum have been published, that of Rowland surpassing all others in the completeness of its details. The number of spectral lines mounts up to thousands. Each special shade of colour corresponds to a definite position in the spectrum, just as each letter from A to Z occupies a definite position in the alphabet. Every kind of light

produced by glowing vapours has a certain wave length which will be refracted through a certain fixed angle, and fall into a definite position in the spectrum. This position is, for every possible kind of light, expressed by a number indicating its wave length.

The light of the Sun gives rise to waves of excessively minute size which travel in ever-widening circles with great speed in all directions through the all-pervading ether of space until finally a few of them are either absorbed, reflected, or trapped by the spectroscope or photographic film. In the latter case they are made to tell their story in the light code, which is unerring in its verdict. The wonderful facts thus revealed far outrival the fascinating theories advanced by Sir William Herschel in the eighteenth century. By means of photographic records of the sunlight obtained with the spectroheliograph, we are enabled to sift out the layer of hydrogen clouds in the atmosphere of the Sun, or peer beneath at the calcium clouds which are at a lower level, and we can keep a record of the cyclonic disturbances taking place in the sun spots from day to day, which can be studied and compared at leisure. Observatories where the Sun is thus subjected daily to the keenest scrutiny are to be found at Cambridge (England), Meudon

(France), Catania (Sicily), Potsdam (Germany), Tortosa (Spain), Kalocsa (Hungary), Zô-zâ (China), Kodaikanal (India), Yerkes, at Williams Bay, Wisconsin, and Mount Wilson in southern California.

In a popular book such as this, further details regarding spectrum analysis would be out of place, but there are many elementary treatises on the subject, such as Professor H. F. Newall's book, *The Spectroscope and Its Work,* for those who wish to take up the matter seriously. The outline given above merely serves to show that our views regarding the Sun may be safely accepted as founded on a basis of actual proved facts.

Recently a Sun tower was erected on the classic hill of Arcetri, Florence, in memory of Galileo Galilei, and was inaugurated in June, 1925. It forms a conspicuous object in the region hallowed by the memories of Galileo, by the famous Torre del Gallo on the crown of the hill where he worked, and by his villa "Gioiello," where he resided for the last ten years of his life, and died in 1642. The tower, which is unique in Europe, is modelled on the two tower telescopes of Mount Wilson, and is due mainly to the efforts of Professors Antonio and Giorgio Abetti, father and son, of whom the latter, now its director, was for-

Hydrogen Flocculi, Photographed with 5-foot Spectroheliograph. Mount Wilson Observatory

merly a pupil of Dr. George E. Hale, the designer and director of the Mount Wilson sun towers.

During the spring of 1926 it was the writer's special privilege to receive an invitation from Dr. Hale to visit the Solar Laboratory equipped with a tower telescope (of Cassegrain type) and a combined spectograph and spectroheliograph having a maximum focal length of seventy-five feet, recently erected in Pasadena for his use. Photographs were shown of this instrument at the June meeting of the Royal Astronomical Society, and the following is an account given in *Nature* for July 3, 1926, by Dr. G. E. Hale, of possibilities in solar research accomplished by means of this new instrument he has termed the spectrohelioscope.

> "Forty years ago," writes Dr. Hale, "I began a series of visual and photographic studies of the Sun. Recently I have returned to this work, after an interval of enforced absence. My instrumental equipment is now augmented by the addition of a spectrohelioscope, a simple device for monochromatic vision which we owe, in its essence, to the pioneers of solar research. This renders visible a host of important phenomena hitherto

concealed from view by the overpowering brilliancy of the Sun's disc. Chief among these are the radiating and absorbing regions of the hydrogen atmosphere, visible with the spectroscope in profile at the Sun's limb, and revealed in projection by spectroheliograms of the disc, but now accessible, wherever they may be situated, to visual observation, with instruments of moderate size."

At the total solar eclipse of 1860, astronomers were not quite certain as to the existence of any solar matter or appendages outside the visible solar globe. Coloured objects had been seen surrounding the black disc of the Moon in total eclipse, like garnets round a brooch of jet, and outside these again the glory of the corona had long been recognised; but astronomers did not agree in regarding these as belonging to the Sun. The eclipse of 1860 will always be notable on account of the demonstration it afforded of the nature of the ruddy flames seen round the eclipsing body of the Moon. The demonstration was effected by De la Rue and Secchi, each of whom succeeded in obtaining several photographs of the total eclipse, showing the dark disc of the Moon at successive stages of its passing across the prom-

Spectroheliogram Showing Brilliant Calcium Flocculi
Photographed at Yerkes Observatory, August 12, 1903

inences or rose-coloured flames. Thenceforth the coloured prominences were recognised by all astronomers as unmistakably solar appendages, and very wonderful they proved, since they were now seen to be not only enormously larger than the brooch round which they seemed set—the globe of our Moon—but to exceed our own earth many times in size. Some of those seen in De la Rue's photographs extended more than 80,000 miles from the Sun's surface; and several of them must have occupied thousands of times as much space as our Earth's globe! A year before this noteworthy discovery had been made, the method of research called spectroscopic analysis had suddenly acquired new and wonderful powers.

Kirchhoff had shown how the dark lines which cross the rainbow-tinted band we call the solar spectrum denoted the presence around the solar orb of the vapours of many elements, such as copper, sodium, iron, hydrogen, and others, with which we are familiar. From this he inferred that the Sun is not only enveloped within a dense and complex atmosphere, but that all round it, and extending a few thousand miles above its surface, there are masses of vapour which cut off the portions of the Sun's light corresponding to the dark lines in the spectrum. But although the

vapours around the Sun thus indicate their presence, yet unquestionably they must themselves be luminous, seeing that not only their position so close to the Sun, but the very fact that they are vaporised, implies an intense heat. Accordingly, it began to be recognised soon after Kirchhoff's great discovery that the coloured prominences, and possibly even the corona, might be composed of those very gases whose presence Kirchhoff recognised by the dark lines in the solar spectrum.

Several years elapsed during which no fresh light was thrown on the solar surroundings. But a circumstance occurred in May, 1866, which, though at first sight it seemed unconnected with the study of solar physics, was destined to lead to very important results. A new star suddenly blazed forth in the constellation of the Northern Crown—or rather a star which had long been shining so feebly as to be visible only with telescopes of some power, acquired suddenly the brightness of a second-magnitude star. It was found to have a peculiar spectrum. The faint rainbow-tinted streak crossed by fine dark lines, forming the usual spectrum of a small star, was observed; but upon this streak, as on a relatively dark background, four intensely bright lines were

seen, in the place ordinarily occupied by the dark lines indicating the presence of the gas hydrogen *absorbing* the brighter light from the star's photosphere. It was manifest that hydrogen surrounded that distant Sun, but that the hydrogen, instead of being relatively cool like that which surrounds our Sun and other suns of the same family (such as Capella, Aldebaran, etc.), was glowing with far greater heat than the Sun which it enveloped. Apparently this star—a Sun like our own Day-star—had suddenly burst into flames. Its lustre, when at its brightest, was estimated at one hundred times its former and present brightness. The Sun which had blazed out in this wonderful manner gradually lost its abnormal brightness, and eventually resumed its position among the stars of the tenth magnitude.

In the meantime a lesson taught by this star had been noted by spectroscopists. Sir Norman Lockyer, in a paper read before the Royal Society in October, 1866, wrote as follows:

> "Seeing that spectrum analysis has already been applied to the stars with great success, it is not too much to think that an attentive and detailed spectroscopic examination of the Sun's surface may bring us much

knowledge bearing on the physical constitution of that luminary. . . . And may not the spectroscope afford us evidence of the existence of the 'red flames' which total eclipses have revealed to us in the Sun's atmosphere, although they escape all other methods of observation at other times? And if so, may we not learn something from this of the recent outburst of the star in Corona?"

In his book, *Contributions to Solar Physics* (p. 578), Lockyer describes how the first steps were taken in opening up a new era in solar physics by means of the spectroscope:

"In my first paper I gave some drawings [of the forms of prominences or solar flames], procured by causing the slit to pass slowly over the prominence. By this means a number of sections of varying length were obtained, which, placed side by side, gave an idea of its shape. The slit then used was extremely narrow, and was radial to the Sun's limb. It was obvious that in this way the true shape of the prominence could not be seen unless the slit were moved with suffi-

cient rapidity to allow of persistent images. At the very outset Janssen and myself attempted to accomplish this, Janssen by giving a rotatory motion to a direct vision spectroscope, I by giving an oscillating motion to the slit, in which I was followed by Young, who afterwards expanded it."

In referring to the examination of the spectra of sun spots and other regions of the photosphere, and repeatedly described reversals and distortions of hydrogen and other lines, by Lockyer and Young, Dr. Hale remarks, in the article in the supplement of *Nature*, for July 3, 1926:

"I can find no indication that the oscillating slit device was ever tested for the observation of the forms of eruptions or other phenomena on the disc. Nevertheless, the credit for building the first spectrohelioscope (as I have named the instrument) and applying it to the observation of prominences at the limb, belongs to my old friend, Professor Young, who was also the first to take photographs of the forms of the prominences through an open slit."

With the spectrohelioscope, one can actually see the flames on the surface of the Sun, recalling the description which has been given of the chromosphere as resembling "a prairie on fire." In that case, the comparison referred to a region of the Sun's gaseous envelope which lies close above the photosphere, but the spectrohelioscope actually shows the flames on the surface of the Sun itself. It seems to answer the query, in a letter addressed by Sir John Herschel in March 1871, to my father, and quoted by him in *Monthly Notices* of the R.A.S. Vol. XXXII., December 8, 1871.

> "I can very well conceive great outbursts of vaporous matter from below the photosphere, and can admit at least the possibility of such vapour being tossed up to very great heights; but I am hardly yet exalted to such a point as to conceive a positive ejection of erupted particles with a velocity of two or three hundred miles per second. But now the great question of all arises: What *is* the *photosphere?* What are these intensely radiant *things*—scales, flakes, or whatever else they be—which really *do* give out all (or at least 99/100ths of) the total light and heat of the Sun? And if the prominences, etc.,

SOLAR PROMINENCES

Photographed at Yerkes Observatory. (The "Maltese" stalking a sparrow

be eruptive, why does not the eruptive force scatter upwards and outwards this luminous matter? I wonder what is going on inside the Sun?"

We have gone far in our knowledge of the Sun since the above query was asked. For instance, we have learned that the eruptive prominences have at times reached elevations of 100,000 or even 400,000 miles, according to Professor Young, and "portions can be actually seen to move, and this implies a real velocity of at least 250 miles a second, so that it is no exaggeration to speak of such phenomena as veritable 'explosions'; of course, in such cases the lines of the spectrum are greatly broken and distorted, and frequently a 'magnetic storm' follows upon the earth, with a brilliant Aurora Borealis." (C. A. Young, *General Astronomy*, Revised Edition, 1904, p. 224.)

Before the eclipse of August, 1868, a general impression prevailed that the prominences do not consist of glowing gas, but the problem of their nature was solved during the eclipse. On that occasion the spectroscope applied to the coloured prominences revealed the fact that they consist of glowing gas. Colonel Tennant, Captain Herschel, MM. Janssen and Rayet in India, and Weiss at

Aden, recognised these bright lines, red, orange, and blue, while Janssen and Rayet saw other fainter lines; and thenceforth it was an assured scientific fact that the solar prominences are masses of glowing gas.

Then followed that episode which is described by my father in an article contributed to the *Cornhill Magazine* for March, 1875:

> "Janssen, during the eclipse, had noted the exceeding brilliance of the prominence-lines, and being, no doubt, familiar with the anticipations of Huggins, Stone, Lockyer, Secchi, and others, he recognised at once the possibility of seeing those lines without the aid of an eclipse. He relates that as the Sun reappeared, and the prominence-lines faded away, he exclaimed, '*Je reverrai ces lignes-là en dehors des éclipses.*' He was prevented by clouds from carrying out his intention on that selfsame day; but on the morrow he was up by daybreak to await the rising of the Sun, and scarcely had the orb of day risen in full splendour above the horizon when he succeeded in seeing the prominences with perfect distinctness. The phenomena of the previous day had completely changed their char-

acter; the distribution of the masses of gas round the Sun's edge was entirely different, and of a great prominence which had formed a most conspicuous feature on the preceding day, 'scarcely a trace remained.' For seventeen consecutive days Janssen continued to observe and make drawings of the prominences, proving that these gaseous masses changed their form and position with extraordinary rapidity. On September 19, or a full month after he had first seen the prominence-lines without the aid of an eclipse, this easy-going gentleman first thought of sending off a paper communicating his discovery to the French Academy of Sciences. It arrived just too late to anticipate an announcement addressed to the same body by Mr. Lockyer, who, on October 16, had succeeded in seeing the lines with the spectroscope. Mr. Lockyer's letter had been read about five minutes before M. Janssen's was placed in the hands of the President of the Academy."

The discovery excited the greatest enthusiasm, and in 1872 the French Government struck a gold medal in honour of the two astronomers, Lockyer being represented on one side of the medal, and

Janssen on the other. Nevertheless, the principles for the spectroscopic method of studying the prominences had been not only explained in full by Huggins a year earlier, but had already been applied by Stone at Greenwich. According to the device suggested by Huggins, as described by Professor Young, in his *Book on the Sun* (page 201):

> "With a spectroscope of sufficient dispersive power it is only necessary to widen the slit of the instrument by the proper adjusting screw. As the slit is widened, more and more of the protuberance becomes visible, and, if not too large, the whole can be seen at once: with the widening of the slit, however, the brightness of the background increases, so that the finer details of the object are less clearly seen, and a limit is soon reached beyond which further widening is disadvantageous. The higher the dispersive power of the spectroscope the wider the slit that can be used, and the larger the protuberance that can be examined as a whole."

The principle of the spectroheliograph with which photographs can be made of the prominences occurred to Dr. George E. Hale in 1889, and

THE "HELIOSAURUS" PROMINENCE
Photographed at the Yerkes Observatory, June 10, 1918

he obtained photographs of prominences with one of these instruments at the Kenwood Observatory in the spring of 1891. In January, 1892, with an improved spectroheliograph, he succeeded in photographing the chromosphere and prominences surrounding the Sun, and the bright flocculi on the disc by the use of the H and K line of calcium. The spectroheliograph not only provides a means of photographing the chromosphere and prominences at the Sun's limb, but has made possible the daily study of the solar atmosphere in projection against the disc. Nevertheless, the need for a similar means of visual observation "persisted for many years," according to Dr. Hale, and his first attempts to observe the hydrogen flocculi visually were made on Mount Wilson with the sixty-foot tower telescope and thirty-foot spectroheliograph soon after the discovery of the Ha vortices in 1908. His efforts were renewed in 1923, but recently the same optical parts now adequately mounted in the new Solar Laboratory in Pasadena (a branch of the Mount Wilson Observatory) have yielded results of the greatest interest.

To quote his own words, (Supplement to *Nature*, July 3, 1926):

"I was agreeably surprised when I first tried this apparatus on January 16 of the present year (1926). I knew from previous experience that the prominences at the limb and the more conspicuous dark and bright flocculi on the disc would be visible, but I was scarcely prepared for the delicate details of structure, both dark and bright, which appeared in good contrast on the disc."

Further on, after a description of the method used, he remarks:

"As a quick and effective means of exploring the entire solar atmosphere the spectrohelioscope is unrivalled. In a few minutes one may run completely around the limb, not only observing the chromosphere and prominences projecting beyond it, but also following with equal ease those which extend on to the disc and appear there as dark absorbing masses. . . . A few minutes' visual observation may now enable one to select interesting regions for special study, or to avoid areas where eruptions, vortices, or other active phenomena may interfere with measurements requiring a more normal state of

tranquillity. Such selections can also be made with the spectroheliograph, but far less quickly and effectively."

Dr. Hale has also found the spectrohelioscope a very useful instrument for the detection of violent outbursts on the Sun such as occurred on January 24 and 25, 1926, preceding the great aurora and magnetic storm of January 26 and 27.* The eruption, which continued for several hours on January 25, surpassed in brilliancy all solar phenomena I have ever seen, and exhibited rapid changes of form.

Dr. Hale concludes the article in *Nature* by expressing the hope that an inexpensive instrument can be built for amateurs, thus greatly multiplying the chances for detecting the exact moments of critical outbursts. A small spectrohelioscope for

*The writer, who was crossing the Atlantic on her way to U.S.A. on the above date, was fortunate that evening in obtaining a splendid view of the auroral display on this occasion as seen from the deck of the S. S. *Orduna*, R.M.S.C. The lower part of the northern horizon was of an inky blackness outlined with white along the upper wavelike edge of a dense mass of threatening clouds resembling snow-capped mountains. Overhead white streaks converged from a point near the Pole Star, spreading outward like the spokes of a fan outlined on a pale green background over which swept clouds of roseate hue as if the sky were on fire. The whole display, brightening and fading at intervals, gradually faded out after an interval of barely half an hour, but of amazing splendour while it lasted.

this purpose is now under construction and will soon be ready for trial. Thus, the actual study of the changes constantly taking place on the surface of the Sun will become a possibility for the amateur enthusiast. What more delightful hobby than tracing the course of the tremendous explosions and outbursts which rend the solar atmosphere, flinging outward glowing masses of gaseous vapour to enormous distances of thousands of miles? His enthusiasm will be aroused by an actual view of cyclonic storms raging on the solar surface, with an intensity compared with which terrestrial storms fade into insignificance.

CHAPTER VII

THE CORONA, THE SUN'S CROWN OF GLORY

ONE by one, the mysterious problems presented by the Sun have been solved. We have learned what it is made of, the conditions under which the substances forming its giant bulk exist, the interpretation of the red flames which are seen round the black disc of the Moon, "like garnets round a brooch of jet," and methods for discerning these objects when the sun is shining with full splendour in the heavens. But one great problem still remained unsolved. When the Sun is hidden from view at the time of a total eclipse, there suddenly bursts into view a crown of glory of light resembling the halo which painters place around the heads of saints. This striking phenomenon had for centuries attracted the attention of astronomers, but they were uncertain as to whether it belonged to the Sun or Moon, or was a phenomenon of our own atmosphere.

The corona was known to astronomers long be-

fore the coloured prominences which have recently received so much attention. Unlike the chromosphere which seems first to have been observed, the corona has been known from antiquity and is described by Plutarch in almost the same terms we should now employ. It has even been supposed that Philostratus refers to the appearance of this object where he remarks, in his *Life of Appolonius,* that "there appeared in the heavens"—shortly before the death of Domitian—"a prodigy of the following nature—a certain corona, resembling the Iris, surrounded the orb of the Sun, and obscured his light." One might conceive that there was no reference here to a total eclipse of the Sun, but Philostratus remarks farther on, that the darkness was like that of night, a circumstance which leaves little doubt that a solar eclipse had taken place. This eclipse has been referred to the year A. D. 95.

It has been mentioned that Halley, in a paper communicated to the Royal Society, alludes to a total eclipse of the Sun which happened at London on March 20, A.D. 1140. In the section of the *Saxon Chronicle** which relates to the events of this year, there appears this statement: "In the Lent the Sun and the day darkened about the noon-

*Ingram's translation of the *Saxon Chronicle,* p. 371.

SOLAR CORONA, SEPTEMBER 21, 1922
Photographed with camera, exposure 16 seconds. Wallal. Lick Observatory Expedition

tide of the day, when men were eating; and they lighted candles to eat by. That was the thirteenth day before the calends of April. Men were very much struck with wonder." It is said that dire consequences followed this event, and the darkness became so great that some feared as William of Malmesbury states that, "the ancient chaos was about to return, and upon going out immediately, they perceived several stars about the Sun."

Total eclipses of the Sun are recorded to have happened in the years, 1187, 1241, and 1495. A remarkable total eclipse of the Sun occurred on June 17, 1433. This eclipse was visible in Scotland, and the time of its occurrence was long remembered by the people of that country as the *Black Hour*. In a manuscript preserved in the library of the University of Edinburgh an account is given of this event. It is said therein that the eclipse took place about three o'clock in the afternoon, and that the darkness was so profound that nothing was visible, manifestly an exaggeration. History makes mention of total eclipses of the Sun which occurred in the years 1485, 1506, 1530, 1544, 1560, and 1598; the last-named eclipse was total in the British Isles. The Moon's shadow passed over the border counties of England and Scotland. The

day of the eclipse was long remembered in both countries as *Black Saturday*. A eclipse which took place in 1652 was also total in the British Isles, and the day of its occurrence gave rise to the expression Mirk Monday among the people of Scotland. Even now it is still used in some parts of that country, although the eclipse itself has long ago been forgotten.

The first total eclipse of the Sun, respecting which the accounts have any pretension to fulness or precision, was one which happened on May 12, 1706. It was observed at Montpellier by Monsieur Plantade, and by other observers at Geneva, Nuremburg and a variety of places. At Montpellier the total eclipse lasted for four minutes and ten seconds. During the time that the sun was totally hidden, there appeared a corona of light around the dark body of the Moon. The planets Venus, Mercury, and Saturn, as well as the bright star Aldebaran and other stars, were visible to the unaided eye. We are told that the effect produced upon birds and animals at the sudden change from day to night was remarkable:

> "The bats flew about as at dusk. The fowls and pigeons betook themselves in great

haste to their resting places. The little birds which sang in cages were silent and put their heads under their wings. The animals which were at work stood still."

At Geneva, totality lasted for three minutes. In the account given by Duillier, (*Phil: Transactions*, 1706, p. 2241, *et seq.*), we read:

"That the Council, which had been engaged in deliberation when the eclipse came, arose from their seats, because it was so dark they were unable to read or write. Bats were seen flying about, and swallows looking in amazement for a place of refuge. In several parts of the city there were seen persons prostrate on the ground and offering up prayers, under the impression that the last day had come. On the tops of some of the mountains of Switzerland where the view of the heavens was not obscured by the mists from the valleys below, the stars appeared as thickly strewn as in the time of full moon. The aspect of the heavens could neither be compared to the darkness of night, nor the chastened hue of twilight." *

**Mem. Acad. des Sciences*, 1706, p. 118.

Captain Stannyan while observing this total eclipse of the Sun, at Berne, in Switzerland, says that just before totality ended, a blood-red streak of light was seen on the left limb of the Sun,

> "which continued not longer than six or seven seconds. Then part of the Sun's disc appeared all of a sudden, as bright as Venus was ever seen in the night, nay, brighter, and in that very instant gave a light and shadow to things as strong as moonlight."

This is probably the first account we have of the red flames.

On May 3, 1715, "a total eclipse of the Sun was observed right across England, from Cornwall and Devon to the Wash, Lincoln. London was included in the totality, which took place soon after nine o'clock on a fine spring morning. This, with the Sun high in the sky, rendered it a sight that Londoners may never expect to witness again." Halley says that "when the last part of the Sun remained on its east side, it grew very faint, and was easily supportable to the naked eye above a minute before total darkness," and that "a few minutes before the Sun was totally hid, there discovered itself round the Moon a

luminous ring," referring to the corona, since he describes it as of a "pale whiteness or rather, pearl colour, a little tinged with the colours of the iris, and concentric with the Moon." During the eclipse, he tells us further, "flashes of light seemed to dart out from behind the Moon. Two or three seconds before the emersion, where the Sun was just coming out, a long and very narrow streak of a dusky but strong red light, seemed to colour the dark edge of the Moon." Jupiter, Mercury, and Venus were seen during totality, also the bright stars Capella and Aldebaran. People in the north of London, which happened to be in the centre of the line of totality, were able to see twenty stars shining as at night. There appeared a luminous ring around the Moon as on the occasion of the eclipse of 1706. "I forbear," says Halley, in his communication to the Royal Society,

> "to mention the chill and damp which attended the darkness of this eclipse, of which most spectators were sensible and equally judges. Nor shall I trouble you with the concern that appeared in all sorts of animals, birds, beasts, and fishes, upon the ex-

tinction of the Sun, since ourselves could not behold it without some sense of horror."

Although this eclipse was visible in England, and though it occurred in the lifetime of so great an astronomer as Halley, no adequate preparations were made for observing it on this occasion. Halley tells us that Coates, a practical astronomer whose observations would have been of high value, was "oppressed with too much company" to pay special attention to the eclipse. Halley himself made a few notes on the phenomenon presented by the totally eclipsed Sun, but we learn nothing new from them regarding the corona. An investigation of newspapers at that period, to be found in the British Museum, discloses the fact that the eclipse passed unnoticed—at any rate by press representatives. Apparently they were more interested in the fact that there was a war on at the time.

On May 22, 1724, a total eclipse was visible in England, France, and Germany, totality lasting for two minutes and sixteen seconds. The planets Venus and Mercury and a few of the brighter stars were visible to the unaided eye, and Dr. Stukeley on Salisbury Plain speaks of great darkness observed during the eclipse (See *Eclipses Past and*

Future, page 65, by Rev. S. J. Johnson.) Among the observers were Maraldi, J. Cassini, at Trianon, and Delisle at Paris. On this occasion a corona of light was seen to encompass the dark body of the Moon during totality. Other eclipses occurred on May 2, 1733, which was visible in the north of Europe; on February 9, 1766, when it was observed in the Southern Ocean by those on board the French warship, the *Comte d'Artois*. The eclipse was total for only fifty-three seconds on this occasion, and "there was seen a luminous ring about the Moon, which had four remarkable expansions situated at a distance of 90° from each other." On June 24, 1778, a total eclipse of the Sun, lasting four minutes, was observed at sea by the Spanish admiral, Don Antonio Ulloa, while passing from the Azores to Cape St. Vincent. We are told that the luminous ring surrounding the Moon presented a very beautiful appearance. Before it became very conspicuous the stars of the first and second magnitude were distinctly visible, but when it attained its greatest magnitude, those of the first magnitude alone could be perceived. The darkness was such that persons who had been asleep in the afternoon (totality began at 3.44 P.M.), awakening, imagined to their great astonishment that the night was already far advanced.

The fowls, birds, and other animals on board took their usual position for sleeping, as if it had been night.

A total eclipse of the Sun depends upon so many circumstances, such as the track of the lunar shadow passing over regions remote from the beaten track, such as Labrador, Sumatra, Easter Island, Siberia, that it may be easily seen that an astronomer may pass his whole lifetime without witnessing so impressive a spectacle.

Even when the conditions are seemingly the best, as at the eclipse of 1923, when the track of shadow crossed Lower California, the "land of sunshine and flowers," the results were disastrous. The instruments numbering fifteen made probably the most complete equipment that has ever been assembled for photographing a solar eclipse. Yet despite all the elaborate preparations, owing to cloudy skies, not a trace of the corona appeared on the photographic plates.

This was the fate of the Mt. Wilson Observatory expedition stationed at Point Loma, shared by seventy astronomers assembled on Catalina Island, including the Yerkes and Harvard parties, and even the Lick Observatory expedition at Ensenada. The usual luck had deserted the Lick party, and conditions at Ensenada "were about as bad as they

could possibly be," according to Dr. S. A. Mitchell, in his book on "Eclipses of the Sun." What a record for sunny California!

Such are some of the ventures made by astronomers, to view a total eclipse of the Sun, which can never last over eight minutes and usually occupies a much briefer interval. Months are spent in preparation after a long journey to the selected spot, and the results, as at the eclipse in Sumatra (expedition sent in 1901 from the Yerkes Observatory), have been *nil* owing to the intervention of clouds at the critical moment.

At the total eclipse of the Sun May 18, 1901, the shadow of the Moon first touched the Earth at sunrise on the east coast of South Africa. It moved rapidly eastward, and passing over the island of Mauritius it crossed the long stretch of the Indian Ocean, not touching land again until it reached the west coast of Sumatra at the town of Padang, at which point it arrived near noon. Crossing Sumatra, it passed over the China Sea and across the island of Borneo, and over Celebes to the coast of New Guinea, whence it left the Earth at sunset.

The long duration of the totality in this eclipse —six and a half minutes on the central line—offered such an opportunity for the study of the

corona as had not occurred since photography had lent its subtle power to the elucidation of the mystery of the corona. Advantage was taken of this extremely favourable chance by several of the leading nations, the English, American, Russian, Dutch, French, and Japanese were represented. Germany alone had sent no expedition.

Sumatra seemed to be the main point for observation, and to it went two English and three American parties, a French, a Japanese, a Russian, and a large Dutch party. Also a party of Jesuits from Calcutta. An English party under Mr. Maunder was located far to the westward on the island of Mauritius, but the larger portion of the observers were located at or near Padang on the west coast of Sumatra. Clouds interfered more or less at all the stations except one—and that one where the chances of clear weather were the poorest.

One of the largest expeditions which went to Sumatra to observe the eclipse was sent out by the United States government from the Naval Observatory under the charge of Professor A. N. Skinner. This consisted of six astronomers of the Naval Observatory, and five others, who became members of the expedition by invitation of the government. The party included the late Pro-

fessor E. E. Barnard of the Yerkes Observatory, and the present abstract of his experience is taken from his account written for *Popular Astronomy*, Vol. IX, No. 10, published December, 1901.

When the eventful date arrived, each one was thoroughly prepared for his special part in the eclipse program, and "should fate have given us a clear sky," as Professor Barnard remarked, "would have nobly performed his duty." A thorough drill had made the manipulation of large photographic plates specially prepared easy and certain.

> "The day of the eclipse dawned unpromising, the sky was more or less covered with clouds. By noon the sky was covered with thickish mackerel clouds, through which the Sun shone feebly. As totality neared it was evident that all our efforts would prove vain. Nevertheless, it was deemed necessary to go through the program in hopes of getting some traces of the corona through the clouds. At the signal for totality each observer carried out his part as if the sky were perfectly clear. During the longer exposures the plates were carefully examined, but no trace of an image could be seen. It was, therefore, evident

that no impression could be obtained. I also went outside the dark room into the open air to examine the progress of the eclipse. The moon could be faintly seen part of the time through the clouds in relief against a feeble coronal ring. Venus and Mercury were plainly visible some distance to the east through a thin place in the clouds. The corona was examined with a small telescope prepared specially for the purpose, but nothing could be made out of it on account of the clouds.

"During totality one was struck with the great amount of illumination. To me the light was similar to that of a heavily overcast day, in which it would have been easy to read ordinary newspaper print without artificial illumination. This in part was doubtless due to the fact that I had been shut up in the dark room for a short time before totality, and that my eyes had in consequence become very sensitive. Perhaps, also, this general brightness was partly due in some way to the clouds which scattered and diffused the sunlight from outside the shadow.

"But the eclipse was over, and the best preparations ever made for the observations

of a total eclipse of the Sun had come to naught. It was with no light heart that the plates were developed. The small, quick-acting lenses which were under the charge of Mr. H. D. Curtis, and which were exposed by Mr. G. E. Irving and two marines, had secured at most the image of the Moon with a thin ring of light about it, and the clouds themselves in the region of the eclipsed Sun. One of the long exposures, indeed, though it showed the clouds well, did not show any trace of the corona. The large plates showed feeble fragments of the chromospheric ring with a few prominences.

"The most exasperating part of it all was, perhaps, the fact that if, instead of going away off into the interior to search for good weather, we had simply gone ashore from the gunboat that carried us to Sumatra and put up our instruments on the seashore or near it, we should have had successful observations, for the ship's people had a fine view of the eclipse with nearly twenty seconds longer duration of totality. But this was something that could not be foreseen, for the meteorological reports had made Solok the most favourable of all the stations.

"One of the most unpromising places in Sumatra, according to the meteorological reports, was Padang-Panjang. It rained there all the time, and there was certainly no chance for observations at that point, so astronomers passed it by, though it was more convenient than any of the other stations in the interior. There was a story told of a Dutchman who lived at Padang-Panjang, who was very anxious to see the eclipse, but he had no faith in Padang-Panjang, and so he came down to Solok to get a view of the corona and missed it; while had he remained at Padang-Panjang he would have seen it, as the sky was splendidly clear there during totality."

To one who contemplates joining an eclipse party it is always more or less of a gamble as to whether one will have success or not; and on this occasion, as Professor Barnard told the writer when relating his disappointing experience, success seemed assured.

An intense interest was aroused at the time of the total eclipse of July 8, 1842, when it was announced that this would be visible in the north of Italy and in the southern provinces of France, Germany, and Russia. Many of the most emi-

nent astronomers of Europe availed themselves of the opportunity for observing the eclipse which was so favourably situated as far as their homes were concerned. M. Arago awaited the display at Perpignan; M. Valz, at Marseilles; M. Petit, at Montpellier; Mr. Baily, at Pavia; Mr. Airy (Astronomer Royal) at the Superga, near Turin; M. Carlini, at Milan; MM. Santini and Conti, at Padua; MM. Schumacher and Littrow, at Vienna; and MM. Otto Struve and Schidlowsky at Lipesk. With all these distinguished astronomers—sentinels, as it were—stationed along the track where the eclipse was observed under most favourable circumstances, detailed statements were bound to give a very fair idea of what one may expect to see on the occasion of a total eclipse of the Sun. M. Arago collected and arranged all the observations of the eclipse, and his own account cannot fail to arouse interest in the reader:

> "At Perpignan, persons who were seriouly ill, alone remained indoors. As soon as the day began to break, the population covered the terraces and battlements of the town, as well as all the little eminences in the neighbourhood, in hopes of obtaining a view of the Sun as it ascended above the horizon. At

the citadel we had under our eyes, besides numerous groups of citizens established on the slopes, a body of soldiers about to be reviewed.

"The hour of the commencement of the eclipse drew nigh. More than twenty thousand persons, with smoked glasses in their hands, were examining the radiant globe projected upon an azure sky. Although armed with our powerful telescopes, we had hardly begun to discern the small notch on the western limb of the Sun when an immense exclamation, formed by the blending together of twenty thousand different voices, announced to us that we had anticipated by only a few seconds the observation made with the unaided eye by twenty thousand astronomers equipped for the occasion, whose first essay this was. A lively curiosity, a spirit of emulation, the desire of not being outdone, had the privilege of giving to the natural vision an unusual power of penetration.

"During the interval that elapsed between this moment and the almost total disappearance of the Sun, we remarked nothing worthy of relation in the countenances of so many spectators. But when the Sun, reduced to a

very narrow filament, began to throw upon the horizon only a very feeble light, a sort of uneasiness seized upon all; every person felt a desire to communicate his impressions to those around him. Hence arose a deep murmur, resembling that sent forth by the distant ocean after a tempest. The hum of voices increased in intensity as the solar crescent grew more slender; at length the crescent disappeared, darkness suddenly succeeded light, and an absolute silence marked this phase of the eclipse, with as great precision as did the pendulum of our astronomical clock. The phenomenon in its magnificence had triumphed over the petulance of youth, over the levity which certain persons assume as a sign of superiority, over the noisy indifference of which soldiers usually make profession. A profound stillness also reigned in the air; the birds had ceased to sing.

"After an interval of solemn expectation, which lasted about two minutes, transports of joy, shouts of enthusiastic applause, saluted with the same accord, the same spontaneous feeling, the first reappearance of the rays of the Sun. To the condition of melan-

> cholly produced by sentiments of an indefinable nature, there succeeded a lively and intelligible feeling of satisfaction, which no one sought to escape from, or moderate the impulses thereof."

In connection with this remark, the following anecdote, which, according to M. Arago, appeared in the *Journal of the Lower Alps*, of July 9, 1842, is of interest. A peasant girl of the Commune of Sieyes was watching her flock when the eclipse began. Entirely unaware of what was happening, she saw with anxiety the gradual darkening of the Sun despite the fact that the sky was cloudless. When the sunlight vanished all at once the girl was terrified, and called aloud for help. She began to weep, and her tears were still falling when the Sun, reappearing from behind the Moon, sent forth his first ray. Reassured at the sight, she crossed her hands, exclaiming in the provincial *patois*, *"O beau Souleon!"* ("Oh, beautiful Sun!")

The interval of time during which the Sun was totally hidden from view behind the dark globe of the Moon was comparatively brief, even at those places which were most favourably situated for observing the phenomenon. At Perpignan,

which was close to the centre of the lunar shadow, totality lasted only two minutes and eleven seconds. At Pavia it lasted a few seconds longer, and at Venice, which was situated near the southern limit of the shadow, it lasted only forty-three seconds. The citizens of Venice remarked, with respect to a steamboat which was passing on the lagoon during the period of totality, that the column of smoke which usually issues from the funnel was no longer visible. The sparks of flame which the column draws along with it appeared in consequence to be isolated, and produced a very beautiful effect.

The appearance presented by surrounding objects during the eclipse was very remarkable. At Narbonne the darkness was described by observers as being "of a wan and livid hue, a shade of greyish olive, which seemed to throw over nature a veil of mourning." At Lodi, the aspect of the heavens, according to Signor Piola, was very striking. There were seen two reddish zones extending along the horizon, one in the southern and the other in the northern region of the heavens. They were of a dull copper colour, totally different from the ruddy hue of the aurora or the twilight. The rest of the heavens passed without any blending to a dark azure inclining to violet. The light

reflected by the waters of river and lake imparted to them an aspect which inspired terror. At Lipesk the heavens appeared of a greyish violet. The stars Aldebaran and Betelgeuse, which are usually red, appeared quite white. It was remarked by all observers that the spectacle presented during totality was of a very appalling nature.

A great number of interesting facts were also noted regarding the sudden transition from day to night, and the effect produced among animals. M. Arago stated that in many instances horses and other animals employed in labour in the fields "halted all at once when the eclipse became total, lay down, and obstinately refused to move in spite of whip or spur." At Montpellier, according to Mr. Lentheric, the bats, thinking that night was come, left their retreats. An owl was seen to leave the tower of St. Peter and fly over a part of the town, doubtless under the mistaken impression that it was night. The swallows sought their nests, the chickens went to roost, a herd of cattle feeding in a field formed themselves into a circle, their heads directed outwards, as if to resist an attack. At Venice, swallows were caught in the streets, the terror with which they were seized depriving them of the power of flight. On the other hand, M. Arago states it to be a well-ascer-

tained fact that the horses employed in the diligences continued to pursue their courses, without seeming to be in the slightest degree affected by the phenomenon.

The effect of sudden darkness during totality was very apparent with certain plants, which closed their leaves as at night. With regard to the variation of the thermometer during the eclipse at Perpignan; a thermometer placed in the shade dropped 3° on the centigrade scale. At Perpignan, Turin, Vienna, and several other places a heavy dew fell during the period of obscuration. It was during this eclipse, by the way, that the phenomenon known as "Baily's Beads" were first observed with attention. These curious appearances were not an actual novelty, as they had been seen in 1791, 1820, and were observed by Baily at Inch Bonney, near Jedburgh, at the annular eclipse of May 15, 1836. The phenomenon arises from the inequalities in the lunar surface; just as totality is approaching, the last narrow crescent of light breaks up into separate portions, giving the appearance of a string of beads. The disappearance of the last bead is generally taken as the commencement of totality and is also the moment for observing the flash spectrum (to be described

later on); the next moment the corona comes into view.

Baily was not an astronomer by profession, but took up the study as a hobby, after he had succeeded in accumulating a fortune making money as a stockbroker. His work is but one of the many instances of the great debt science owes to the amateur astronomer. In the description given by Baily, he states that when the cusps of the Sun were about 40° asunder, a row of lucid points, like a string of bright beads, irregular in size and distance from each other, suddenly formed round that part of the circumference of the Moon that was about to enter on the Sun's disc. Its formation was so rapid that it presented the appearance of a row of pearl beads, separated by dark intervals.

"My surprise was great," he says, "on finding that these luminous points, as well as the dark intervening spaces, increased in magnitude, some of the contiguous ones appearing to run into each other, like drops of water; for the rapidity of the change was so great, and the singularity of the appearance so fascinating and attractive, that the mind was for the moment distracted and lost in the contemplation of the scene, so as to be unable to attend to every minute occurrence. Finally,

pursued her course, these dark in-
ces (which at their origin had the
lunar mountains in high relief, and
which still continued attached to the Sun's bor-
der) were stretched out into long, black, thick,
parallel lines, joining the limbs of the Sun and
Moon; when all at once they *suddenly* gave way
and left the circumference of the Sun and Moon
in those points, as in the rest, comparatively smooth
and circular; and the moon perceptibly advanced
on the face of the sun."

The result of this experience was to stimulate his interest in the physical aspect of eclipses, with the result that we find him full of enthusiasm at the time of the total eclipse already referred to, which was total over central and southern Europe on July 8, 1842. He had set up his Dollond's achromatic (three and one-half feet focal length) in an upper room of the University of Pavia, and was eagerly engaged in noting a partial repetition of the "beads" seen by him in 1836, when he was "astounded by a tremendous burst of applause from the streets below, and at the same moment was electrified at the sight of one of the most brilliant and splendid phenomena that can be well imagined. For at that instant the dark body of the Moon was suddenly surrounded with

a corona, or kind of brig[illegible] glory and relative magnitude to [illegible]hat whic[illegible] round the heads of saints, and which [illegible] is called an *auréole*. Pavia contain[illegible]a [illegible] thousand inhabitants, the major part of whom were, at this early hour, walking about th[illegible] streets and squares or looking out of windows, in order to witness this long-talked-of phenomenon; and when the total obscuration took place, which was *instantaneous*, there was an universal shout from every observer, which 'made the welkin ring,' and for a moment withdrew my attention from the object with which I was immediately occupied. I had indeed anticipated the appearance of a luminous circle round the Moon during the time of total obscurity, but I did not expect, from any of the accounts of preceding eclipses that I had read, to witness so magnificent an exhibition as that which took place.

"The breadth of the corona, measured from the circumference of the Moon, appeared to me to be nearly equal to half the Moon's diameter. It had the appearance of brilliant rays. The light was most dense (indeed, I may say quite dense) close to the border of the Moon, and became gradually and uniformly more attenuated as its distance therefrom increased, assuming the form of

diverging rays in a linear line, which at the extremity were more divided and of an unequal length; but in no part of the corona could I discover the regular and well-defined shape of a ring at its *outer* margin. It appeared to me to have the Sun for its centre, but I had no means for taking any accurate measures for determining this point. Its colour was quite white, not pearl colour, nor yellow, nor red, and the rays had a vivid and flickering appearance somewhat like that which a gaslight illumination might be supposed to assume if formed into a similar shape. . . . Splendid and astonishing, however, as this remarkable phenomenon really was, and although it could not fail to call forth the admiration and applause of every beholder, yet I must confess that there was at the same time something in its singular and wonderful appearance that was appalling; and I can readily imagine that uncivilised nations may occasionally have become alarmed and terrified at such an object, more especially at times when the true cause of the occurrence may have been but faintly understood and the phenomenon itself wholly unexpected.

"But the most remarkable circumstance attending the phenomenon was the appearance of *three large protuberances* apparently emanating from

the circumference of the Moon, but evidently forming a portion of the corona. They had the appearance of mountains of a prodigious elevation; their colour was red tinged with lilac or purple; perhaps the colour of the peach blossom would more nearly represent it. They somewhat resembled the snowy tops of the Alpine mountains when coloured by the rising or setting Sun. They resembled the Alpine mountains also in another respect, inasmuch as their light was perfectly steady and had none of that flickering or sparkling motion so visible in other parts of the corona. All the three projections were of the same roseate cast of colour, and very different from the brilliant vivid white light that formed the corona; but they differed from each other in magnitude. . . . The whole of these three protuberances were visible even to the last moment of total obscuration, at least I never lost sight of them when looking in that direction, and when the first ray of light was admitted from the Sun, they vanished, with the corona, altogether, and daylight was instantaneously restored" (*Memoir R.A.S.*, Vol. XV, pp. 4-6).

These "red flames" were even discerned by Mr. Airy with the naked eye. "Their form" (wrote the Astronomer Royal) "was nearly that of saw-

teeth in the position proper for a circular saw turned round in the same direction in which the hands of a watch turn . . . their colour was a full lake red, and their brilliancy greater than that of any other part of the ring" (*Memoir R.A.S.*, Vol. XV, p. 16).

During the total eclipse of December, 1870, a remarkable discovery was effected by Professor C. A. Young, which my father had predicted several months before in the first edition of his book, *The Sun*, then in press. In a note at p. 295 of that treatise (proof sheets to page 384 were in the hands of some of the observers who went to Spain) my father wrote, "there may be an atmosphere including the vapours of iron, sodium, magnesium, etc. (of all the elements, in fine, whose dark lines appear in the solar spectrum), extending, say, one hundred miles above the photosphere, and yet no instruments we possess could suffice" (he referred to observations made on the uneclipsed Sun) "to reveal any trace of its existence, *unless the dark lines in the solar spectrum be thought to demonstrate the fact that such an atmosphere actually does exist.*"

At the total eclipse of 1870 Professor Young, determined to test this question as to whether a shallow but exceedingly rich and complex envelope

exists immediately above that glowing surface which we call the Sun, made a remarkable discovery. It was manifest that by treating a solar eclipse as, so to speak, an extension of ordinary instrumental means for analysing the Sun's light, he might recognise the existence of an envelope too shallow to be dealt with at other times. The Moon would act like a dark cover, gradually hiding more and more of the Sun, until, for a few moments, the whole of the photosphere, but not the shallow envelope, would be concealed.

For a few seconds during which the Sun was thus concealed, the shallow envelope, if such existed, remaining still visible, light would be received from the latter alone, and whatever the nature of this light, or, in other words, whatever the character of the envelope, the spectroscope would make its meaning clear. It happened just as Professor Young had expected. He had placed the slit of his spectroscope so as to include a linear space forming a tangent to the Sun's disc, and he found that at the moment of obscuration, and for one or two seconds later, the field of the instrument was filled with bright lines. The rainbow-tinted streak crossed by dark lines, which constitutes the solar spectrum, had disappeared the moment the true photosphere was completely con-

cealed, and at this instant there flashed into view multitudinous bright lines of all the colours of the rainbow. Each dark line on any point of the rainbow-tinted solar spectrum had been changed as though by the power of a magic wand into the bright line of the colour of that part of the spectrum. So that it was clear that the envelope thus discovered is formed of the same gases which produce the dark lines of the solar spectrum; or rather, it was clear that the dark lines are formed by the absorptive action of this envelope, though the gases present in it are really glowing with intense brilliancy. It is only by comparison with the still more intense light of the solar photosphere that the lines corresponding to these gases appear dark. The "flash" spectrum was the name invented by Sir Norman Lockyer for this very beautiful phenomenon, which has since formed a very important place in the eclipse programs, from both the photographic and the spectroscopic standpoint. In fact, some astronomers, notably Dr. S. A. Mitchell, Director of the Leander McCormick Observatory, at the University of Virginia, devotes a whole chapter in his recently published book, entitled *Eclipses of the Sun*, to a discussion of the flash spectrum.

He tells us, that "half a century of remarkable

progress in solar physics since Young discovered the flash spectrum does not witness any decided unanimity of opinion regarding the exact location of the solar envelope wherein lies the absorption causing the Fraunhofer lines. On the one hand appears Young's original view that the reversing layer is a thin shell but a few hundred miles in thickness, while on the other extreme we have Lockyer's opinion that such a reversing layer does not exist, and that the corona is merely the cooler and rarer portion of the chromosphere. Although observations taken at the time of an eclipse must be relied upon for the chief information by means of which this question can be settled, still there are many other lines of investigation that contribute their results towards the same problem. The flash spectrum may be observed visually or photographically, with or without a slit, and by means of prisms or gratings."

A spectrum is said to be "reversed" when lines seen previously bright on a dark background appear dark on a bright background. The "reversing" layer is immediately beneath the chromosphere, but mingles gradually with it, so that the two seem to blend. In fact, it may be regarded as the lower layer of the chromosphere. It is found to extend up to a height varying from about 6,000

to 14,000 kilometres above the photosphere. The reversing layer to which most of the lines of the flash spectrum are due has a depth of from 600 to 1,000 kilometres (since a kilometre equals five-eighths of a mile, this is equivalent to a depth of from 375 to 625 miles).

A description of the methods used for obtaining photographs of the flash spectrum can be found given in detail in Chapter XIII of Dr. Mitchell's up-to-date work on the subject, and he gives some idea of the great difficulty always experienced by eclipse observers in securing sharp focus with their spectroscopes. "In fact," as he states, "one very prominent feature of eclipse spectra in the past has been the continued succession of photographs poorly focussed. One method of securing focus, frequently made use of, has been to apply the final adjustments by utilising the spectrum of the disappearing crescent of the Sun a few minutes before totality. During the excitement and nerve-racking tension of these moments, a perfect adjustment can be obtained in this manner only as the result of a happy accident—and this method should never be resorted to under any circumstances."

Observe, then, how complex are the Sun's surroundings, compared with the glowing orb in

which astronomers formerly believed. The analysis of sun spots has revealed the fact that the central nucleus of the sun is probably gaseous, this being indicated by its low mean density and its high temperature—enormously high even at the surface, where it is coolest. Surrounding this main body of the Sun is the photosphere, a shell of incandescent clouds, formed by the condensation of vapours which are exposed to the cold of space. These photospheric clouds float in an atmosphere containing still uncondensed, a considerable quantity of the same vapours of which they themselves have been formed, just as in our own atmosphere the air around a cloud is still saturated with water vapour. This vapour-laden atmosphere, probably comparatively shallow, constitutes the "reversing" layer, above referred to, and by its selective absorption produces the dark lines of the solar spectrum, while by its general absorption it probably causes the darkening at the edge of the limb of the Sun. Mingling with the vapours of the reversing stratum in the region near the photosphere are the permanent gases composing the chromosphere and prominences which are composed mainly of hydrogen and helium. The prominences usually rise to far greater elevations than the vapours, sometimes to a height of thousands of miles. Resting

on the photosphere, but extending to a distance of millions of miles beyond, in the case of its outer boundary, is the corona, one of the most striking and imposing of all the phenomena of the solar system. To quote my father's words in the conclusion of his essay on "The Sun's Corona," in his book entitled *Mysteries of Time and Space*, "It is a fitting crown of glory for that orb which sways the planets by its attraction, warms them by its fires, illuminates them by the splendour of its light, and pours forth on all of them the electric and chemic influences which are as necessary as light and heat for the welfare of their inhabitants."

CHAPTER VIII

WHAT IS THE CORONA?

WHEN it was found that the Sun was the centre of a system of wonderful envelopes rising higher and higher above his glowing surface until they merge into the corona, a new interest was taken in total eclipses of the Sun, the only time during which it is possible to observe this wondrous phenomenon. The Sun casts behind the Moon a long pencil of shadow, and when the two bodies are in line and the Moon is near enough to the Earth, the shadow trails eastward over its surface. For all those who are so fortunate as to be within the narrow track of darkness which can never exceed 167 miles in width, but may be thousands of miles in length, a view of the corona may be obtained during the few moments of totality, which can never exceed eight minutes. Though the Moon is 400 times smaller than the Sun, yet at such times the Moon is 400 times nearer than that luminary, so that Sun and Moon both appear nearly of the same size in the heavens.

A slight variation in the size or the distance of the Moon from the Earth, would make a total eclipse of the Sun impossible.

A simple illustration of the appearance of the shadow projected in space was afforded to the eager spectators in London, on the occasion of the partial eclipse of the Sun on January 25, 1925, when a novel sort of eclipse was caused by the drifting between them and the Sun of the ill-fated *R. 33*, which a few weeks later so lamentably came to grief. The shadow of the airship silhouetted against the shadow caused by the eclipse was a small replica of the shadow cast by the Moon on a larger scale, and like it, ended in a tapering peak. Since the body of the Moon is so much smaller than that of the Sun, the shadow of the former is always necessarily a cone, with sides converging to a point or apex.

When the moon comes directly between the Sun and the Earth, the cone is of such a length that the apex sometimes nearly reaches the Earth's surface, and sometimes is rather longer than is necessary to reach the Earth. Which of these phenomena takes place depends on the relative distance of the Sun, Moon, and Earth. If at the time of the eclipse the Moon is farther from the Earth than its mean distance (which is

238,840 miles), it is obvious that on the average the shadow will not reach the Earth. If at the time of eclipse the Moon is farther from the Earth than its average distance, the cone is too short to reach the Earth, and in consequence the angular magnitude of the Moon is then less than that of the Sun; hence results an annular eclipse, so called from the annulus or ring of the Sun's disc round the Moon when the eclipse is at its greatest phase. On the other hand, if the Moon when between us and the Sun is nearer to the Earth than its mean distance, the shadow is then long enough to reach the Earth, and the Moon's angular diameter is now slightly greater than that of the Sun. In this case a total eclipse is the result.

Mathematicians work out such problems as to how far the Earth is immersed within the cone of darkness, and the consequent breadth of the track of shadow, which the Moon traces as with the point of a pencil, along the Earth's surface during its passage from west to east between us and the Sun. They let us know by how much the Moon's edge will overlap the edge of the Sun, the beginning, duration, and end of the total phase, through what latitudes and longitudes, whether on land or sea, the track of shadow will pass, and

intending observers are given the following important items regarding the four contacts to be observed at a total eclipse of the Sun.

The first is when the edge of the Moon apparently touches the edge of the Sun. It is then of interest to begin watching for the change which will gradually take place in the appearance of the landscape until the second contact, when the Moon hides the Sun from view and the eclipse becomes total. At this instant the marvellous corona flashes out, but within a period of a few minutes it vanishes from sight. At the third contact the first ray of sunlight makes its appearance and gradually the sunlight resumes its sway, until by the fourth contact the Moon finally leaves the disc of the Sun. From the first contact to the fourth, the duration may be about three hours for any particular station.

The Moon advances along its path at the rate of nearly 2,100 miles an hour, and were it not for the Earth's rotation this is the rate at which the shadow would pass the observer, but allowance must be made for the fact that the Earth is rotating towards the east in the same general direction as that in which the shadow moves. As its surface moves at the rate of about 1,040 miles an hour at the equator, an observer at some place thereon,

with the Moon near the zenith, would be passed by the shadow with a speed of about 1,060 miles per hour, a velocity equal to that of a cannon ball.

In higher latitudes, where the velocity of the Earth's rotation is less, the relative speed of the shadow is higher; and where the shadow falls very obliquely, as it does when an eclipse occurs near sunrise or sunset, the advance of the Moon's shadow along the Earth's surface may become exceedingly swift—as great as 4,000 or 5,000 miles per hour. The weird effect of this swift onrush of shadow has been most graphically described by an observer, Forbes, as quoted by Professor Langley in his book, *The New Astronomy* (page 38): "The reader who has ever ascended to the Superga, at Turin, will recall the magnificent view, and be able to understand the good fortune of an observer (Forbes) who once had the opportunity to witness thence this phenomenon, and under a nearly cloudless sky. 'I perceived,' he says, 'in the southwest a black shadow like that of a storm about to break, which obscured the Alps. It was the lunar shadow coming towards us.' And he speaks of the 'stupefaction'—it is his word—caused by the spectacle. 'I confess,' he continued, 'it was the most terrifying sight I ever saw. As always happens in the cases of sudden, silent, un-

expected movements, the spectator confounds real and relative motion. I felt almost giddy for a moment, as though the massive building under me bowed on the side of the coming eclipse."

Another witness, who had been looking at some bright clouds just before, says: "The bright cloud I saw distinctly put out like a candle. The rapidity of the shadow, and the intensity, produced a feeling that something material was sweeping over the earth at a speed perfectly frightful. I involuntarily listened for the rushing noise of a mighty wind." It seems a fitting prelude to the swift and sudden appearance of the mysterious corona, which at all other times eludes our view.

Various attempts have been made to observe or photograph the corona at other times than during a total eclipse of the Sun, but so far without success. In my father's book, *The Universe of Suns*, page 84, published in 1884, he made the following suggestions, regarding the means which may be employed to show the solar corona without an eclipse:

> "When we analyse the light of the corona with the spectroscope we find that the greater portion is, like the light of the sky, of all the colours of the rainbow. It is true that during

the total eclipse of June, 1869, the American astronomers found that a part of the corona's light is of a special tint of green; and this observation was confirmed during the eclipse of December, 1870. But it was evident, from the faintness of these tints and the existence of a rainbow-tinted background, formed by the spectroscopic dispersion of the rest of the corona's light, that only a very minute proportion of the total light from the corona was of this special tint. In later eclipses it was shown that the green tints (for another had been detected) are not even always present. In 1871, during the second Indian eclipse, it was proved that a considerable portion of the corona's light is reflected sunlight, for the dark lines peculiar to sunlight were seen by Janssen in the spectrum of the corona.

"At this stage of the inquiry matters had not a very hopeful aspect. I had myself made suggestions respecting the corona, which, had a larger share of its light belonged to a specific green tint, might have led to the corona being seen as desired. I proposed that the light from the Sun, and the region around him, should pass through a green ab-

sorptive medium (solid or liquid), and then form an image in the usual way on a screen, only that the screen should be of the precise colour of the green coronal tint we are considering. The part of the screen on which the Sun's image would fall in this way was to be cut away—that is, a suitably sized circular hole cut out of the screen—so that his overwhelmingly brilliant rays should not tax the eye, strained to detect, if possible, the faint light of the corona. But there would have been little chance, as I pointed out, that the mere use of a green absorptive medium and of a green reflective surface would make the corona visible. My main reliance had been on spectroscopic dispersion. I hoped that the illuminated card, if examined through a spectroscope adjusted to the green coronal tint, would show the corona, just as we see a prominence through a spectroscope adjusted to the red, or to the orange-yellow, or to the greenish-blue prominence tint.

"But this method never really had a chance of success. The green tint of the corona is altogether too faint to show the corona without an eclipse, as was shown in 1871, by the circumstance that it will not

give an image of the coro[illegible]n during totality. It seemed, till May, 1882, that astronomers must give up all idea of seeing the corona except during the occasions of eclipses. But during the eclipse of May 17 the spectrum of the corona was photogra[illegible] and a peculiarity was thus indicated again renewed the hope that the corona m[illegible] be systematically studied. The photog[illegible] showed that the part of the corona's lig[illegible] which belongs to the violet end of the spectrum is much stronger than the rest. There is no definite tint of violet which includes a considerable portion of the coronal light, but there is a general superiority of strength throughout the indigo and violet parts of the coronal spectrum.

"This being so, the spectroscopic method applied to the prominences could not be applied to the corona. That this is so, will be seen at once if we consider the matter in the light of Newton's experiment, as we have already considered the visibility of the prominences. Taking sky light and prominence light together, we had a rainbow-tinted spectrum formed by multitudinous tints of light from the sunlit sky, along which three

pr[illegible] images could be seen—one in the red, one in the orange-yellow, and one in the green-blue. Taking sky light and coronal light together, we should have a rainbow-tinted spectrum from the sky light as before, and in addition a rainbow-tinted spectrum stronger in the violet part, from the corona. We might or might not be able to detect the relative excess of violet light; but whether we did or not, we should see nothing of the coronal figure. If the rainbow-tinted spectrum of the sky light were entirely removed, as during total eclipse, for instance, no *image* of the corona would be seen in this way, for the relatively strong violet parts of the coronal spectrum which would be seen would be made up of multitudinous violet images blended indistinguishably together.

"But although the spectroscopic method would not be in this way available, the absorptive method—that is the use of coloured media—would apply very favourably to this case. For while we know of no absorptive media that allow only light of certain definite tints to pass through, we can always find a medium which will allow all excess of light

of any of the spectral colours to pass while the other colours are absorbed. We can test the absorptive qualities of various media for this purpose most exactly by means of the spectroscope; for the mere colour of a medium, as judged by the eye, is no sufficient test of its absorptive capacity for particular spectral tints: a medium green to the eye may be found under spectral analysis not to suffer green rays to pass—to be opaque to such rays—but to let yellow and blue rays pass in such proportion as to produce the observed green light.

"Selecting suitable violet absorptive media, Dr. Huggins * thought of trying to see the corona by means of its excess of violet light. 'It appeared to me by no means improbable,' he writes,

'that the corona' (after its light had been thus sifted) 'would be able so far to hold its own against the atmospheric glare, that the parts of the sky immediately about the Sun, where the corona was present, would be in a sensible degree brighter than the adjoining

*Sir William Huggins, a noted English astronomer, born in 1824, died 1910. He is described as being the leader in spectroscopic investigations regarding stars and nebulæ.

parts, where the atmospheric light alone was present.'

He did not, however, thus see the corona. He saw reasons for not attempting thus to see it. 'It was obvious,' he says,

'that in our climate and low down on the Earth's surface, even with the aid of suitable screens, the addition of the coronal light behind would be able to increase but in very small degree the illumination of the sky at those places where it was present'—

which is another way of saying that it would be impossible to discern the form and figure of the corona. Then, again, the portion of the light on which reliance was placed, namely, the violet, is not such light as our eyes are readily able to deal with so as to recognise small differences of illumination. It is much easier to detect slight differences in the brightness of red, yellow, or green light, than corresponding differences in violet light.

"It occurred then to Dr. Huggins that he would attempt what, if he succeeded, would

be of far greater value. There was another consideration of importance. He remarks:

'The corona is an object of very complex form, and full of details depending on small differences of illumination; so that, even if it could be glimpsed by the eye, it could scarcely be expected that observations of a sufficiently precise character could be made to permit of the detection of the more ordinary changes which are doubtless taking place in it.'

What, then, Dr. Huggins planned was from the first to use photography, which possesses extreme sensitiveness in the discrimination of minute differences of illumination. It also possesses, Dr. Huggins notes, the enormous advantage of furnishing from an instantaneous exposure a permanent record of the most complex forms. 'I have satisfied myself,' he says,

'by some laboratory experiments, that, under suitable conditions of exposure and development, a photographic plate can be made to record minute differences of illumination

existing in different parts of a bright object, such as a sheet of drawing paper, which are so subtle as to be at the very limit of the power of recognition of a trained eye, and even, as it appeared to me, of those which surpass that limit.'

"To increase his chance of success, Dr. Huggins soon substituted a reflecting telescope for the refracting instrument he had at first employed. He used a Newtonian reflector, having a mirror six inches in diameter. We need not describe the contrivances used to obtain on the photographic plate an image of the region around the Sun (and the Sun itself) after absorption of all but the violet light; for the description would not be intelligible except to those familiar with photographic telescopy. The violet medium employed was at first violet glass (that is, not merely flushed with a violet tint, but the glass itself so tinted); afterwards a new and strongly made solution of potassium permanganate in a glass cell with carefully polished sides.

"After some trials Dr. Huggins satisfied himself that on every one of the plates an

appearance strikingly resembling the corona could be detected. He would have waited until more distinct images had been obtained; but, as he truly says, our climate is very unpropitious for such observations, and very few intervals, even of short duration, occur in which the atmospheric glare immediately round the Sun is not very great. He therefore thought it best to describe his results at once, so that his method might be applied in other countries where the conditions are more favourable. In the meantime the results he actually obtained were very promising.

"The work was begun at the end of May, 1882, and the photographs were obtained between June and September. On twenty of them the coronal form appears. It does not consist merely of increased photographic action around the Sun; but there are distinct coronal forms and rays, admitting of measurement, and of drawings being made from them, in the best plates. The agreement in plates taken on different days, with different violet media, with the Sun in different parts of the field, and attention being given to other necessary precautions, would seem to make it evident that the real corona was

photographed, and not an optical phantom, the result of mere instrumental effects. There are some who think that the Sun's bright rays, received on the glass and reflected from the back of the plate, have produced forms simulating those of the Sun's coronal radiance. But after carefully considering the precautions employed by Dr. Huggins, one of the most cautious and careful physicists living, I find it impossible to regard this explanation as admissible.

"The plates taken with very short exposure show the inner corona only, but its outline can be clearly seen when the plates are examined under suitable illumination. Increased exposure showed the curved rays and rifts peculiar to the outer corona, while the details of the inner corona were lost. 'In the plates which were exposed for a long time,' says Dr. Huggins,

'not only the Sun but the corona also is photographically reversed; and in these plates, having the appearance of a positive, the white reversed portion of the corona is more readily distinguished, and followed in its irregular sinuous outline than in the case of

those plates where the Sun only is reversed, and the corona appears as in the negative, dark.'

"The opinion of those best qualified to judge is that Dr. Huggins has really accomplished the difficult task he attempted; that at last we have the means of obtaining not only views, but permanent records of this great solar appendage. Professor Stokes, most cautious of physicists, regards the appearance on the plates as 'certainly very corona-like,' and is 'disposed to think it probable that it is really due to the corona'; which from him is equivalent to the expression of strong conviction on the part of any other physicist. Captain Abney, after careful comparison of the photographs with those obtained during the eclipse of May, 1882, goes so far as to say that if Dr. Huggins's photographs do not represent the real corona, those taken during the eclipse do not, either. Dr. Huggins himself, respecting whom I may say that a long experience assures me that he himself would be the severest critic of his own work, says that there remains little doubt that by the method described in his paper, but

'under better conditions of climate, and especially at considerable elevations, the corona may be distinctly photographed from day to day with a definiteness which would allow of the study of the changes which are always going on in it.'

By an adjustment of the times of exposure, either the brighter part of the corona near the Sun or the fainter exterior rays, could be obtained as might be desired.

"Then, too, there is good reason to believe that the method itself may, with practice and experience, be greatly improved. The sensibility of photographic plates, whether wet or dry, is being increased year after year. With advantage taken of every advance in experience, both respecting the corona itself and respecting the photographic art, we may well hope that the method thus happily inaugurated will be more and more successfully applied, until at last, taking advantage of the numerous observatories existing in the Old and New World and both north and south of the equator, we shall have daily records of the figure and changes of figure of the corona, and shall be at length enabled to

determine its real structure and significance." *

To sum up the results of the efforts made by Dr. Huggins in 1882, to avail himself of the power of the photographic plate to solve the problem of making observation of the corona a possibility at other times than during total eclipse of the Sun, twenty plates were secured between June and October, 1882, which showed forms closely resembling the corona, not merely in a general brightening near the Sun, but in the presence of distinct coronal forms and rays . . . a careful agreement of the photographs with those secured at the Egyptian eclipse of the same year showed so perfect an agreement of general features and even details as to convince both Dr. Huggins and Captain Abney that the problem had been solved.

In 1884, a committee appointed by the Royal Society sent Mr. Ray Woods to the Riffelberg, near Zermatt, for the purpose of continuing the experiments made by Dr. Huggins, and the station selected was at an elevation of 8,500 feet. The best results were obtained on the clearest days. During the next two years no experiments in this direction were made in England, owing to the

**The Universe of Suns*, pp. 84-90.

presence of whitish skies. In 1886, however, the method was put to the test at the time of the total eclipse of that year, on August 29.

Captain Darwin photographed the Sun on the day before the eclipse, but the coronal images obtained showed no similarity with the true coronal images photographed during totality. On the day of the eclipse exposures made during the partial phases showed a false corona, part of which was in front of the Moon. In no case did the images show the Moon eclipsing the corona. Instantaneous exposures made during totality gave no trace of the corona. Although the conditions were most unfavourable during this eclipse, Captain Darwin concludes "that the result tends to show that a practical method of obtaining photographic records of the corona during sunlight is not likely to be obtained," at the same time remarking that he does not consider it proved that the method is impossible.

At Cape Town Dr. Gill photographed the partial phases of the same eclipse with a Huggins coronagraph, but the results were equally disappointing. Professor Ricco made a large number of photographs of the Sun's surroundings with a Huggins coronagraph constructed by Grubb. Many of these show distinct coronal forms, ex-

tending to great distances from the solar limb. During the partial eclipse of April, 1893, Professor Ricco made several exposures, but the coronal forms shown on the negatives cross the dark body of the Moon without interruption, thus demonstrating that they do not represent the true corona. . . . It is, therefore, highly probable that the coronal images obtained with the Huggins apparatus on Mount Etna were of terrestrial origin.

Professor S. P. Langley, in his report of the Mount Whitney Expedition, gives the following account of his experience when searching for a method to render the corona visible to the eye, or to secure its image upon a photographic plate, without the aid of a total eclipse. After describing the sky at Mount Whitney, as of a deep violet blue, and absolutely cloudless, with only a slight orange tint about the horizon at sunset, he portrays his observation as follows:

> "Carrying a screen in the hand between the eye and the Sun, till the eye is shaded from the direct rays, it can follow this blue up to the edge of the solar disc without finding in it any loss of this deep violet or any milkiness as it approaches the limb. It is an incomparably beautiful sky for the ob-

server's purpose, such as I have not seen equalled in the Rocky Mountains, in Egypt, or on Mount Etna. . . . I found that I could choose a position on the north of the cliff, along whose edge the Sun was moving nearly horizontally; so that the shadow was fixed as regards the observer, and so sharp that, though I must have been over one quarter of a mile from the portion of the cliff casting it, I could, without moving from my place, and by only a slight motion of the head, put the eye in or out of view of the Sun's north limb. The rocks were, in these circumstances, lined with a brilliant silver edge, due to diffraction. This I had anticipated, but now I saw what could not be seen by screening the Sun with a near object, that the sky really did not maintain the same violet blue up to the Sun, but that a fine corona was seen about it of about 4° in diameter, nearly uniform, though it was sensibly brighter through the diameter of 1½°. Upon bringing to bear upon it an excellent portable telescope, magnifying about thirty times, I found it was composed of motes in the sunbeam, between the diffracting edge and the observer's eye. This result, if disap-

pointing, is also interesting from another point of view, as showing that the dust shell which encircles our planet exists at an altitude of at least 13,000 feet, and under favourable conditions for the purity of the atmosphere." *

Professor Langley made another attempt to photograph the corona without the aid of a total eclipse of the Sun, from Pike's Peak in Colorado, over 14,000 feet high. The summit of the Peak is covered with great angular boulders of splintered granite, and observations were made under exceptional difficulties but without success.

At the Rochester Meeting of the American Association, Dr. Hale described a new method of coronal photography, as follows:

"By the aid of the spectroheliograph I had succeeded in photographing the chromosphere and prominences as well as the faculæ and other phenomena on the solar disc. On June 10, 1892, I made two attempts to photograph the corona with the spectroheliograph, the exposure being much longer than that re-

*Report of the Mount Whitney Expedition, p. 41. S. P. Langley.

quired for prominences. The sky showed a considerable brightening near the Sun on the plates, but no certain indication of the corona was obtained. The possibilities of the spectroheliograph in its application to the photography of the corona were carefully studied, and in August of the same year the construction of a special instrument for this purpose was undertaken by the mechanician of the Kenwood Observatory. It was first proposed to isolate light of any desired wave length by means of a spectroheliograph, and thus to photograph the sky surrounding the Sun, employing such a region of the spectrum as experiment proved to be best adapted to show the corona on the background of the sky.*

"Reasoning from Professor Vogel's measures of the solar absorption, as Dr. Huggins had previously done, and also from the comparative brightness of the coronal spectrum in the violet region, it would appear that the upper part of the spectrum might be advantageously employed, except when the blueness of the sky extends to the very limb of the Sun. Professor Langley's observation at Mount Whitney would make it appear

**Astronomy and Astrophysics*, 1893, p. 260.

probable that this latter condition is never fully realised. M. Deslandres has recently called attention to Lord Rayleigh's comparison of the sky and solar spectrum, from which was deduced the law that the brightness of the sky spectrum (near the zenith) is inversely proportional to the fourth power of the wave length of the region observed. With an atmosphere free from large particles of dust and vapour the law would probably hold for the light of the sky very near the Sun's limb, and in such a case the less refrangible region would be advantageously employed with the spectroheliograph. Under ordinary conditions, however, the whiteness of the sky near the Sun is so intense as to render advisable the use of the blue or violet rays, partly on account of the lack of really satisfactory photographic plates sensitive to the red or ultra-red rays.

"But further reflection convinced me that the mere isolation of a particular region of the spectrum by means of the spectroheliograph would not suffice for the difficult task of photographing the corona in full sunlight, and it was soon concluded that the most promising means of attaining this end was

offered by the dark lines of the solar spectrum. As the light of the sky is merely reflected sunlight, the dark lines of its spectrum indicates that light of the corresponding wave lengths is but feebly represented in our atmosphere. If, then, a dark line (other than telluric) in the sky spectrum is set on the second slit of a spectroheliograph, and the slit narrowed sufficiently to exclude all light except that of the line, it is evident that the protection to the photographic plate will be the same (neglecting the effect of diffuse light in the apparatus) as that which would result from a reduction of the brightness of the whole sky to that of the line. Whether or not the coronal light will be reduced in anything like the same proportion is the next question to be considered."

Experiments were made at Kenwood Observatory in the spring of 1893, and on June 16 of that year Professor Keeler and Professor Hale, accompanied by Mrs. Hale, left Chicago on an expedition to Pike's Peak for the purpose of carrying out these experiments, in an attempt to photograph the solar corona without the aid of a total eclipse. After summing up the difficulties experienced,

Professor Hale, writing from the Kenwood Observatory, University of Chicago, September 7, 1894, gave the following suggestions for future work:

> "While it can hardly be said that the results of my various attempts to photograph the corona without an eclipse have been at all encouraging, I have by no means abandoned hope that the method,* if fairly tried under good conditions, may yet be successful. In choosing a site great care should be taken. On Pike's Peak the dust was very troublesome, and a small bellows was therefore provided to be used on Mount Etna to blow the dust from the mirror during the exposure. There was much more dust on Etna than on the Peak, and the bellows would have been useful had it been possible to carry out the proposed experiments on the corona. A snow-covered peak might offer important advantages in this and in other particulars. The season chosen should naturally be not far from the summer solstice, but the local meteorological records should be consulted

*Description given in *Astronomy and Astrophysics* for 1894, under title, "*On some Attempts to Photograph the Solar Corona without an Eclipse.*"

before fixing the time. An altitude of at least 13,000 feet should be selected, and the higher one goes the better. A low latitude would naturally be preferred to a high one, on account of the altitude of the Sun.

"In conclusion, I may say that the investigation has been a fascinating one, in spite of its succession of failures. On account of the importance of discovering some means of observing the corona without an eclipse . . . it is to be hoped that others may think it worth their while to continue the attack on this difficult problem."

Writing in 1925, over forty years after Dr. Hale's appeal, the problem still remains unsolved. According to Dr. H. Spencer Jones in his *General Astronomy* (dated, 1924), page 134, in his remarks concerning the corona, "no method has been discovered by which it can be observed at any other time than during totality." While authoritative, this dictum need not necessarily be final. By one of those happy accidents which sometimes lead to great discoveries, some experimentalist may hit upon the exact method which has so far eluded scientists in their search for the magic key. When found it should unlock the portal behind which

the wonder of the corona remains hidden, except during the brief interval when the glory of the Sun is totally eclipsed.

In his book on *The Sun*, dated 1913, Professor R. A. Sampson writes (page 118):

> "During the past twenty years the Sun has been eclipsed for perhaps half an hour in all, but it is not an exaggeration to say that every second has been turned to account. An eclipse camp represents probably the greatest concentration of thought and activity that is anywhere to be seen. The two minutes or three minutes of duration are plotted off in advance, so many seconds to each exposure with each telescope, so as to secure longer and shorter exposures, with different plates for each instrument. Helpers stand on either side of the astronomer, handing him the fresh plates for exposure, and receiving those he has exposed. Seconds are counted in a loud voice from the first signal given—the disappearance of the crescent of the Sun, which as the Moon crosses the last portion of the disc, runs rapidly together and vanishes. Before the day all this is rehearsed several times so that there shall be no hitches or surprises.

There are, unfortunately, futile eclipses, but there is little fault to be imputed to the astronomers. Now the Sun cannot be studied properly while we leave one of its phenomena out. If we knew all about the corona, or if there were any other way of observing it, we might be less insistent for the use of every eclipse; but while the case is otherwise, the many failures in the past from bad weather are only an argument to let no possible future opportunity be missed for increasing our knowledge."

To sum up, despite the great variety of different methods used in attempting to photograph the corona in full sunlight, many of the ablest astronomers engaging in the quest, the goal seems as far distant as ever. "The task to be overcome is to separate the light of the corona from the strong illumination of the sky. The chief names connected with this work are those of Hale, Ricco, Deslandres, Wood, and Hansky. . . . The observations by Abbot in 1908, and those by Kunz and Stebbins in 1918, have shown the cause of the failures," according to Dr. S. A. Mitchell, a noted authority on the subject, "namely the intrinsic feebleness of the corona. Even in the

brightest parts, the inner corona is no brighter than the surface of the full Moon, which has a brilliancy six hundred thousand times less than the Sun. The corona is about equal to the intensity of the illuminated sky at eight or ten degrees distant from the Sun, but close to the Sun's edge the light of our central luminary is so overpowering that it appears indeed well-nigh impossible to photograph the corona in full daylight. As a consequence, knowledge of the corona will advance very slowly, since the opportunities afforded for investigating it will come only at the very rare intervals of total eclipse of the sun." *

Regarding the light of the corona, much of it, as we have already seen, is reflected sunlight, its envelope consisting partly of glowing gas of an element unknown in terrestrial chemistry which has been named coronium, a line in the green part of the spectrum. This is usually very prominent in the coronal spectrum, but in the eclipse of 1914 it was scarcely visible, a previously unknown line in the red region having pride of place, being very prominent. So the mystery deepens, and in answer to the query, "What is the corona?" our knowledge is meagre, but considering the limited period during which such

*_Eclipses of Sun_, page 365. S. A. Mitchell.

knowledge can be acquired is this surprising? With increased development of scientific apparatus and new methods of investigation, a way to photograph the corona in full daylight may be discovered, giving the astronomer ample opportunity for learning the inner secrets of the corona.

CHAPTER IX

PERSONAL EXPERIENCES IN VIEWING THREE TOTAL ECLIPSES OF THE SUN

AT THE time of a total eclipse of the Sun, each observer notices something which may escape the attention of another, and the following experiences will give an idea of what may be seen even when one is unprovided with telescope, camera, or such like aid. There is much that an amateur can observe from the picturesque standpoint, which the astronomer is debarred from enjoying, owing to a prearranged program dealing with important technical work—telescopic, photographic, or spectroscopic—demanding his entire attention. The writer once heard a well-known astronomer remark that although he had joined two or three eclipse expeditions, yet he had never *seen* the corona, so that in a way the amateur is fortunate in being free to observe it in comfort, although such observation may have no actual scientific value.

At any rate, such was the writer's experience in

1896, when viewing the total eclipse of the Sun, on August 9, of that year, an experience which left an indelible impression on the mind, and aroused an enthusiasm in the study of astronomy which has never abated from that day to this. No one can behold the wonders of a total eclipse of the Sun without an overwhelming feeling of awe and a dim realisation of the marvellous structure of the corona. Its wonders are hidden from all but the few fortunate mortals who may happen to be within the pathway along which the shadow rushes like a mighty wave, plunging that part of the world into temporary gloom. Then flashes forth the filmy, pearly-hued corona, and as swiftly vanishes after a brief revelation of mysterious grandeur unsurpassed. No poet has as yet found fitting words to describe this marvel, nor painter depicted its wonders so as to convey an adequate idea of a scene—visible for a few fleeting seconds —and then lost to view in the glare of sunlight, until the next total eclipse of the Sun.

Little knowing what the display would mean, the writer accepted an invitation to join a party of tourists from U.S.A. who intended visiting Norway, Sweden, Russia, and Denmark, during the summer of 1896, with the total eclipse of the Sun as an additional and unusual attraction. The

date was August 9, and the track of shadow on this occasion crossed Norway, Nova Zembla, and Siberia, ending beyond Yezzo, an island of Japan bordering the Sea of Okhotsk. Arrangements had been made for our party to observe the eclipse from Bodö, a small village on the western coast of Norway, twenty miles south of the Lofoden Islands, but on arrival there the day before the eclipse we were informed that it would be necessary to climb the Lobsaäs, a hill 2,000 feet high if we wished to observe the eclipse. As the eclipse started at an early hour, 4 A.M. Norway time (3 A.M. Greenwich mean time), and as our main object was to observe the corona which would be visible for less than two minutes, several members of our party objected. They signed a petition in which they expressed the desire that Captain Boggs of the S.S. *Ohio*, in which we had embarked for the voyage, would take us to a more desirable site where climbing hills would not be a necessity. Looking over his chart, he found that the track of shadow passed over the Kunnen promontory, ten miles south of Bodö, and not far from the lighthouse island of Stöt, and he accordingly made arrangements to take us there in time to observe the eclipse.

An exasperating yet amusing incident occurred

to an observer who remained in Bodö and ventured to climb the Lobsaäs. His fate was most tantalising, according to the report given by E. W. Maunder F.R.A.S. in the *Daily Graphic* for August 28, 1896. He had intended making an attempt to obtain a series of photographs of the corona during totality. Accordingly, he made all the necessary arrangements and climbed the Lobsaäs, attended by a Lapp porter who carried his camera for him. Unfortunately, the sudden approach of darkness just before totality so terrified the Lapp that he ran away, taking the camera with him, and all efforts to trace him or the camera were of no avail.

Our own experience was more fortunate, though, as already stated, it was of no value so far as scientific research was concerned. On the morning of the eclipse we were awakened at two o'clock by the sound of a gong, and after a hurried breakfast we hastened on deck. Our first glances were turned in the direction of the sky, which was of the deepest blue, and clear save for a few fleecy white clouds, edged with the palest pink, hovering over the ocean towards the west. Behind the intervening hills gleamed a rosy light merged in the golden mist of sunrise. The Sun had risen a few degrees above the horizon and a golden

radiance overspread the tints of sea and sky. It scarcely seemed possible that soon the light of the Sun would be entirely hidden from view, and doubts were audibly expressed within the hearing of the writer, who apparently would have been held responsible had the eclipse not taken place on scheduled time. However, promptly at 2.58 (Greenwich mean time 3.58) attention was called to a black notch on the upper right margin of the Sun's disc, and soon the Moon became plainly visible to all who were observing it with smoked glasses, as it gradually obscured the Sun. Slowly the surrounding landscape lost its brilliant colour. The Arctic Ocean all around us was calm as a summer lake, and the breezes setting towards land were almost balmy. On the summit of mountains bordering on the Kunnen promontory rested a mass of grey clouds. Soon the mountains were partly lost in shadow, and the sheen of the ocean had dwindled to a narrow pathway. Meanwhile, a silvery radiance overspread the tints of sea and sky. It is impossible to describe the weird effect produced by this strange unearthly light. It can be compared only to the rare glow one sees when the Sun comes out slightly obscured after a thunderstorm. This silvery light faded into a more

sombre hue, and the faces of the spectators looked ghastly in the waning light.

The air became decidedly chilly, and suddenly the darkness seemed literally falling from above like a curtain let down from the sky. A star flashed into view near the zenith, and then, seemingly alarmed at its own temerity, shyly veiled itself in mist, but as our eyes became accustomed to the gloom we could see it again twinkling brightly. It was a strangely fascinating sight for those who were watching the swiftly approaching darkness, which apparently caused alarm among the sea gulls which had been circling around our ship. They flew away, screaming, not returning until after the eclipse was over.

The merest outline of a crescent Sun was now to be seen, like a weird sickle in the sky. The temperature had fallen several degrees, and in silence and gloom we awaited the moment of totality. No need of warning, for a repressed but universal cry, which echoed from one end of the ship to the other, announced that the moment of totality for which we had waited so anxiously had arrived. There hung the Moon like a dark globe in mid-air, while instantaneously all around it flashed the glorious indescribable corona. No painter ever wielded brush that could reproduce

that matchless silvery glow. We could have gazed entranced for hours, but we must count the precious time by seconds, for totality lasted but one minute thirty-five seconds, or ninety-five seconds in all. Scarlet prominences glowed like rubies against the dazzling white of the inner corona. Beyond this streamed the silver rays of the outer corona, distinctly outlined against a sky of greyish hue. The streamers directed from the solar poles were shorter and less brilliant than those extended eastward, while westward a streamer reached a distance equalling three times the diameter of the sun.

The planets Mercury, Jupiter, and Venus shone with great brilliancy, while the first-magnitude star Regulus gleamed with silvery radiance. Just before totality ended, the western limb of the Moon was outlined for a brief second with a vivid red light, and next moment the Sun burst forth in a blaze of glory and the corona vanished, but that impressive scene lasting but one minute and thirty-five seconds is one that can never be forgotten. It seemed as though we had paused for a moment on the threshold of the Infinite, obtaining a fleeting glimpse of the glories beyond!

Within half an hour after totality, clouds drifted across the Sun, resembling in arrangements

the cloud belts surrounding the planet Jupiter. The stars and planets had faded from view and the Sun gradually resumed its splendour. Just before the last contact, clouds were still drifting in the direction of the Sun, so that we had to watch most carefully in order that we might detect the exact moment of the final contact. By that time the sky was nearly covered with clouds and we realised by what a narrow margin we had escaped the failure experienced by the eclipse party stationed at Vadsö further north.

But the dream of our long voyage was over, the stars paled in the Sun's lustre, and the sea gulls that had been frightened away by the darkness again circled round our ship. The passengers exchanged significant glances with each other with a meaning too deep for words. The chilliness in the air was replaced by warmth, though the Sun was now temporarily eclipsed by clouds. Our ship, which had been at anchor throughout the eclipse, from the first to the last contact, now swung slowly towards the south and our thoughts flew over land and sea, toward Vadsö, where Sir Robert S. Ball and members of the British Astronomical Association had gathered in force.

Alas! their experience, as described by the great astronomer, was most disappointing. To quote his

own words, from the account published in *The Times* for August 19, 1896:

> "The weather during the week had not been such as to give us much encouragement. Some days had been fine, some had not, and I rather think the latter were the majority. However, we hoped for the best, and after no little labour on the part of the astronomers all was ready by Saturday evening. But I do not think there was much sleep for anyone that night. We were all full of expectation, and those who had any duties of observation to perform had to leave the ship at 2 A.M., so as to be at their posts well before the phenomena commenced at 4 [Norway time; 3 A.M. Greenwich mean time].
>
> "Our first glance as we came up was, of course at the sky. The decks (of the *Norse King*) were still wet with the heavy rain which had fallen in the night, and the clouds were still threatening. There were, however, some breaks, which gave us hope. I went up through the town and found all the inhabitants astir. A stream of them were wending their way up the road to the hill where the Observatory was placed. Indeed, I think

that almost all the adult population must have turned out for the purpose. This will seem somewhat less surprising if it be borne in mind that we were in a part of the world where the day and night are curiously mixed, and where, in fact, the seconds of the total eclipse expressed the duration of the only darkness which had been experienced during the summer. Among the spectators were mostly Lapps who stood in circles round each of the encampments, gazing with more curiosity perhaps on the strange people who had come so far to see so little, than on the sights of the heavens.

"The instruments were duly opened, for it was decided that, no matter what happened, the contemplated program should be faithfully carried out. I was stationed at a small equatorial telescope of three-inch aperture. It was with some hope that we saw a partial clearance of the sky and the Sun peeped forth. But I failed to see the first encroachment of the Moon on the Sun's limb. A cloud prevented that, though almost immediately after I could see the advance of the Moon and thus learn that the eclipse had actually commenced. For an hour we had

one glimpse after another of the resistless march with which the dark Moon entered straight on the brilliant disc. Beautiful, indeed, were the cusps of light as they grew steadily narrower. For a long time there was but little appreciable effect on the general illumination of the earth. It was not until about four-fifths of the Sun's disc was obscured that I became conscious of the increasing gloom of the landscape and felt as if some tremendous thunderstorm was approaching. Gradually the interest and the excitement augmented as the solar crescent became narrower and narrower. It was still only to be seen occasionally, and even then only through clouds. At last the crescent had become perceptible, as a thin line, and some hopes were indulged that it would remain visible up to the supreme moment of totality. But, alas! just as the crescent began to shorten and approach the vanishing point the clouds through which my vision was straining closed in again. I found it impossible to distinguish this extinction of the light from the extinction of totality itself, and thus I was led to believe that totality had been reached some seconds before the actual moment. Those

who were not engaged as I was at the telescope had a more accurate method of determining its advent by the advance of the shadow. Miss Klumpke was, however, so fortunate as to be able to note the exact moment through her telescope, and this is, at least, one valuable observation which is doubly acceptable amid the almost universal failure.

"Of the phenomena characteristic of a total eclipse, namely, the corona and the prominences, not a trace was to be seen. Not until after the precious 106 seconds had long expired was the Sun again seen as a crescent on the other side. The plates were duly exposed, no doubt, but as the Sun itself was not able to pierce the canopy, it need not be expected that its faintly luminous appendages could send a single ray to a plate. It has thus to be admitted that the object with which the elaborate instruments were transported with so much trouble to Vadsö has been entirely defeated.

"But there are certain phenomena of a total eclipse which do not depend on the corona and the prominences, and these other phenomena are in themselves so interesting

and so striking that I feel heartily glad that I came to witness so sublime an event. I know that many others who are with us share the same opinion. The approach of the shadow is a spectacle of unparalleled magnificence, and from our situation at Vadsö many of the party were most favourably placed for its observation. The eclipse took place when the Sun was east and the shadow advanced from the west. To reach us it had to travel within sight of the observers at Vadsö, for many miles over a mountainous district, and then for many miles down the fjord.

"Mr. Crommelin succeeded in finding the commencement of totality by the approach of the mighty shadow as a dark curtain drawn over the sky, while the end of totality was sufficiently manifest by the sudden lightening up which so many observers in this as in other eclipses have noted. The duration of totality appears to agree with that predicted, but the beginning and the ending appear to have been about three seconds before the tabular time. This will not be considered as much difference when it is remembered that it only corresponds to a departure of the

TOTAL SOLAR ECLIPSE, AUGUST 9, 1896
Photographed by W. Shackleton, Baden Powell Expedition at Nova Zembla. Coronagraph. Aperture 4⅝ inches. Exposure 40 seconds

Moon centre from the tabulated place by an amount which is less than a ten-thousandth part of the Moon's apparent diameter.

"Mr. Wesley and Mr. Green both testify to the artistic beauty of the phenomenon of totality; they were struck by the indigo-purple colour of the clouds and the amber-yellow light between, while at the horizon, tints resembling those of the setting Sun were extremely beautiful.

"It must be confessed that the results of scientific interest are very meagre, but to many of us the occasion has been one of much interest and profit in indirect ways. There has been great opportunity for the interchange of ideas, and those in charge of elaborate instruments have been most kind in permitting others to learn their use. The attempt made to observe the eclipse has been a gallant one, and if so much well-meant effort has not borne all the fruit that we might have wished, it has, at all events, tended to show that astronomy was never before cultivated with the same vigour that it is at present. We must hope for better luck next time. Shall I add in conclusion that the

morning after the eclipse was one of cloudless beauty?"

Successful observations were made by a party of Russian astronomers who went to the little village of Sükavuopio, which is about halfway between Bodö and Vadsö. Moreover, important photographs were secured in Nova Zembla by Sir Baden Powell and some of the members of the British Astronomical Association. These photographs provided a remarkable confirmation of an observation made by Professor C. A. Young, at the total eclipse of the sun in 1870. The observation is only possible under peculiar circumstances. According to this theory, as stated by Professor Young in his book entitled *The Sun*, page 82·

> "At a total eclipse of the Sun, at the moment when the advancing Moon has just covered the Sun's disc, the solar atmosphere of course projects somewhat at the point where the last ray of sunlight has disappeared. If the spectroscope be then adjusted with its slit tangent to the Sun's image at the point of contact, a most beautiful phenomenon is seen. As the Moon advances, making narrower and narrower the remaining

sickle of the solar disc, the dark lines of the spectrum for the most part remain sensibly unchanged, though becoming somewhat more intense. A few, however, begin to fade out, and some even turn palely bright a minute or two before the totality begins. But the moment the Sun is hidden, throughout the whole length of the spectrum; in the red, the green, the violet, the bright lines flash out by hundreds and thousands, almost startlingly; as suddenly as stars from a bursting rocket-head, and as evanescent, for the whole thing is over within two or three seconds. The layer seems to be only something under a thousand miles in thickness, and the Moon's motion covers it very quickly."

This theory, now well established, had been disputed by Lockyer, but oddly enough was confirmed at the total eclipse of 1896, by photographs taken by Mr. Shackleton, one of his own assistants. Mr. Shackleton occupied a station near Vadsö on the Varanger Fjord, and he was not only successful in obtaining photographs of the solar spectrum, but in timing his observations with the prismatic camera so well that the long-desired photograph of the "flash" spectrum was at last secured. Simi-

larly, immediately after totality, the "flash" spectrum may again be observed. Moreover, unlike the corona, the "flash" spectrum does not require a total eclipse of the Sun to make it visible. According to Professor R. A. Sampson, writing in 1913, "at a partial eclipse in 1912, when the Sun was reduced to a very narrow crescent, the horns of which turned round the disc as the Moon moved across its face, it was noticed by Professor Fowler and by Professor Newall that just at the tip of the horns the bright line spectrum could be picked up. Formerly it had only been seen for a few seconds at the beginning and end of each total eclipse. The difference is important, because by going just outside the line of totality in a total eclipse the cusps showing the flash spectrum may be followed for an hour or more, so that leisurely arrangements, high dispersions, gratings, and narrow slits—all that goes to make exact the observations of the spectrum of the limb—may be brought into service." *

For amateurs, it is interesting to note, as stated by Dr. S. A. Mitchell, Director of the Leander McCormick Observatory, Va., U.S.A., that "the flash spectrum may be observed visually, or photographically, with or without a slit, and by means

*_The Sun_, p. 116. R. A. Sampson.

of prisms or gratings." * He also gives another valuable hint regarding the plan for securing photographs of the "flash" spectrum at the proper times:

> "A pair of binoculars is used. Over the right half, a direct-vision spectroscope is employed. Jewell constructed the Naval Observatory instruments and utilised a plane grating and plane mirror for the direct vision spectroscope. As it was possible to employ any particular portion of the spectrum one wished, that section extending from blue to green was brought into the field of view. With a pair of binoculars and such an attachment, it was possible with the left eye to watch the disappearing crescent of the Sun, shielding the eye, if necessary, by smoked glass, while with the right eye the emission lines could be watched as they appear one after the other with the approach of second contact. Armed with this, the first flash can be observed, and the exposure started with great nicety. For the second flash the exposure should begin at least five or more seconds before the calculated end of totality, and

**Eclipses of the Sun*, p. 213. S. A. Mitchell.

should terminate with the first trace of the reappearing Sun." *

This reference to observations of the "flash" spectrum may seem a divergence from the subject matter indicated at the head of this chapter, but it is of interest as showing one more item which can be added to the program of an amateur who may be planning observations of a total eclipse of the Sun for his own personal satisfaction. To conclude the account of the eclipse of 1896, the expedition led by Professor Todd, at the time Director of the Amherst Observatory, U.S.A., had a rather unfortunate experience. They had planned to observe the eclipse at Yezzo in Japan, which was well within the track of shadow. However, on arrival at Yezzo, they were advised to go further inland, as it was apt to be misty on the coast. Thinking the people at Yezzo would know more about their climate than he did, Professor Todd accepted their advice with disastrous results, for at the station selected the sky was overcast with clouds on the day of the eclipse and the corona remained hidden from view. On returning to Yezzo, it was learned that the sky there had been

**Eclipses of the Sun*, p. 218. S. A. Mitchell.

clear of clouds during the eclipse, and a magnificent view of the corona had been obtained!

Eclipse Expedition, May 28, 1900

During the year 1900, a total eclipse of the Sun occurred on May 28. The pathway of shadow came in contact with the Earth on the Pacific coast of Mexico, and crossing the northwestern part of the Gulf of Mexico, continued in a northeasterly direction over Mississippi, Alabama, Georgia, South Carolina, North Carolina, reaching the Atlantic Ocean at Cape Henry in Virginia. The chief towns near the central line of shadow were Columbus in Georgia, Raleigh in North Carolina, and Norfolk in Virginia. Leading observatories in the U.S.A. had representative expeditions stationed along the central pathway of shadow. The writer was invited to join the expedition sent by Columbia University, New York City, to observe the eclipse from Virginia Beach, Norfolk.

Leaving Norfolk at 6 A.M. on the morning of the eclipse, we arrived at Virginia Beach about five minutes past seven. Arrangements were made for observing the approaching shadow, the landscape effects, and the elusive shadow bands, while the photographer of the party selected a suitable

site for his camera. The sky was blue and almost cloudless, the air warm and pleasant, but the temperature fell several degrees during the hour preceding the eclipse. At 8.23, we noticed the first contact, and within a quarter of an hour the changing appearance of the sky became evident. Its blue tint slowly merged into grey, though in the immediate neighbourhood of the Sun the sky remained comparatively bright. The colour effects were specially impressive as they were reflected in the deep blue of the Atlantic, which faced us, our observing station being the sandy beach. Where the sky and horizon met, a soft blend as of sunset hues gradually changed to a deep orange hue merging into violet, extending as far as the blue-grey background against which the Sun was outlined. When it was half hidden by the eclipsing Moon, the sky assumed an ashen hue as at eventide. The swallows began circling overhead as though alarmed at the darkness. The twittering of the birds in the nearest trees, calling to their little ones, showed that they were under the mistaken impression that it was evening. A negro coming from an adjacent field feebly urged the mule he was driving to hurry, and we could see him casting terrified glances at the sky which momentarily grew darker. It was a scene well

TOTAL ECLIPSE OF THE SUN, MAY 28, 1900
Photographed by E. E. Barnard with horizontal telescope (with coelostat). Aperture 6 inches. Exposure 30 seconds.

fitted to alarm the ignorant, and to impress those who knew its meaning with a strange feeling of awe, as at something uncanny.

When the Sun was a little more than half covered, we amused ourselves noting the crescent shapes assumed by the reflection of the light of the Sun as it sifted through the leaves of the trees. As we were on the beach, we gathered some branches of sweet bay that we found growing here and there, and holding these over a white sheet we had prepared for our observations of the shadow bands later on, we saw clearly outlined, crescent-shaped patches of light instead of round patches usually seen when the Sun is not eclipsed. In this way it was possible to observe the gradually narrowing crescents and follow the progress of the encroachment of the Moon on the Sun, without looking at the actual eclipse in the sky. A mere pinhole pricked in a paper through which the sunlight filtered produced exactly the same effect, in miniature. The explanation thereof is simply that light proceeding from any object, and passing through a small opening, throws an image of the same shape as itself. Thus, if a beam of sunlight passes through a hole in a window blind or shutter, its image is seen on the floor or wall

of a room as a round patch of light, the same shape as the Sun.

About ten minutes before totality we began to make arrangements for observing the shadow bands which make their appearance just before and after totality. Two white sheets were placed on the ground, and just a moment before totality these strangely elusive, flickering shadow bands drifted rapidly over the white surface prepared to receive them. They resembled the faint and indistinct outline one sees of the rippling waves of a calm, sunlit sea reflected on the walls of a state-room on a steamer in motion. Their rapidity of motion has been compared to that of a fast-flowing tide. The rippling movement appeared to be from left to right—that is, in the general direction northeast to southwest. They seemed to be two inches wide and the same distance apart, but Todd describes them as sometimes "eight inches broad and two or three feet apart, at another only one or two inches broad and ten or twelve inches apart. They travel at one time as fast as a man can run, and again with the velocity of an express train." These fleeting shadows are probably due to irregularities in atmospheric refraction of the slender beam of light coming from the waxing and waning crescent.

At the moment of totality the shadow bands vanished and the dense shadow of the Moon swept over us like a mighty wave encircling us in its gloom. The purplish hue of the sky was reflected on the waves as they rippled along the beach, the purple merging into a deep orange hue near the horizon. The Sun was now entirely hidden from view by the Moon, around which glowed the dazzling white inner corona merging into the silvery rays of the outer corona outlined against the sky. Not a cloud to mar the picture! The coronal streamers extended outward in the direction of planet Mercury, and beyond glowed planet Venus in all its splendour.

On returning to Norfolk, we were informed that all the inhabitants had turned out to observe the eclipse. Every available camera was used for the purpose of obtaining photographs of the corona, and telescopes were levelled at the Sun to good purpose. Shortly before, during and after totality, five-minute observations were made to determine if the eclipse had affected the weather, with regard to changes in temperature, dew-point, humidity, and wind or clouds. Although such observations were left to the meteorologists, yet we could not help noting, during the progress of the eclipse, that the air became chilly and that a

breeze sprang up from the direction of the Atlantic. The direction was indicated by a streamer fastened to a staff placed in an exposed spot on the beach. The ground was covered with dew at the time when only a slender crescent of sunlight remained visible, a minute or so before totality. The writer, who had placed her gloves on the ground, preparatory to making notes regarding the shadow bands, found them damp with moisture as if they had been out all night in the dew, when she picked them up after the eclipse was over.

Total Solar Eclipse of August 30, 1905

The next eclipse observed by the writer was that of August 30, 1905. On this day the eclipse began in Manitoba, and after crossing through northern Canada it left Labrador about 8 A. M. on its way across the Atlantic. Shortly after noon the shadow crossed Spain, then on through the Mediterranean, northern Africa, and Egypt leaving the Earth's surface at sunset on the Indian Ocean. Spain was chosen by the majority of astronomers, both because the duration of totality was longer and on account of the reputation Spain has always had for sunny weather. Therefore, along a path 120 miles in width running diagonally across the

Peninsula, hundreds of astronomers of all nationalities were gathered.

It must be stated to the credit of the Spanish government, that as early as 1901 the officials at the Madrid Observatory under the able direction of Don Francisco Iniquez, began to make definite preparations for the eclipse. Firstly, by the issue of a very good map of the path of shadow across Spain; and secondly by means of maps and a pamphlet containing valuable suggestions and advice. Don Iniquez proved untiring in his energy and the patience with which he accomplished the self-imposed task of removing any obstacles which might have proved a barrier to the success of those who had come to Spain to observe the eclipse.

After making definite arrangements for observations which were to be made of the partial eclipse at Madrid, Don Iniquez went to Burgos for the purpose of directing the final program planned for the observation camp at Campo de Lelaila. This was situated at a distance of a mile and a half from Burgos and 150 feet above its level. Twelve tents were erected here, representing as many nationalities, American, French, German, Spanish, Scotch, etc., and the British Astronomical Association including seventeen members under the direction of Mr. Thwaites, F.R.A.S.

The writer had come all the way from New York, to join the party, but had missed connection therewith in London, and was held up a week at San Sebastian, owing to a misunderstanding about the ticket through Spain which should have been sent there, instead of to Madrid where it was afterwards traced by the shipping firm in New York. However, as the time for the eclipse was drawing near, another ticket was purchased, and the writer arrived in Burgos two days before the day of the eclipse.

Our train was packed to its utmost capacity and on arrival the passengers mingled with the crowds thronging the streets. They had come from far and wide, some walking miles to be present at the arrival of the King of Spain, who had arranged to visit Burgos during the week of the eclipse. We waited until the next train steamed slowly into the station, and as the King stepped on to the platform, "El Rey! El Rey!" could be heard from the crowd of excited peasants. Flags waved over the principal buildings, and decorations hanging from the windows made a veritable gala display. The King took up his residence for the time being in the Carthusian monastery on the outskirts of the city.

Next day, he visited Campo de Lelaila, review-

ing the arrangements, as it were, and inspecting with much interest the instruments and telescopes to be used during the eclipse. He conversed affably, and with the greatest ease with the directors of each expedition, in their own language, no easy matter where so many different nationalities were concerned. During his visit to our tent there was a slight shower of rain, so that he was detained nearly half an hour, during which time he was entertained by the members of our party who had made him welcome. Naturally a most cordial greeting was given to him by the Spanish astronomers, over whose tent floated the Spanish colours.

The morning of the eclipse promised fairly well, despite the gathering of a few ominous-looking clouds low down in the western horizon. However, later on, they caused great anxiety as they gradually spread over the sky until the Sun was entirely hidden from view, and a shower of rain tended still further to depress the onlookers. To an observer, not interested in the vital point at issue, the display of cameras and telescopes shielded by umbrellas, and the woebegone look on the faces of the astronomers, must have presented a strange aspect.

Every moment our chances of seeing the corona lessened, and anyone who has experienced the dis-

appointment can realise what it meant, to have travelled thousands of miles with the possibility of failure at the critical moment. Through occasional gaps in the clouds we managed to get a glimpse of the Sun when it was a little more than half eclipsed. Then the clouds drifted over it, hiding it completely from view, and our hopes again went down to zero. Meanwhile, the sky near the western horizon assumed a purplish hue, and the northwestern sky was flooded with a vivid orange tint streaked with a few silvery clouds as at dawn. A range of hills in the distance was partially shrouded in mist, their summits dimly visible in the fast waning light. Plainly could be heard the hum of voices, and we learned later that the excited peasants who had approached as near to our camp as they dared were praying aloud to all their favourite saints asking them to roll the clouds away so that the astronomers might see the eclipsed Sun. Mounted officials provided by the government had considerable difficulty in keeping unwelcome intruders within bounds, but as the moment of totality drew near the excitement subsided and the busy hum of voices sank to a low murmur.

Despite the falling rain and cloud-covered sky each member of our expedition was prepared to

General View of Camp Lelaila, Burgos
Photographed by A. E. Oakes, August, 1905

perform his assigned task. Darker and darker grew the scene, the approaching shadow coming like a vast purple cloud, edged with an amber hue of wondrous beauty. Gradually it assumed the appearance of a gauze veil of ever-thickening folds let down from overhead rather than the onrushing wave so frequently described. Five minutes before totality the rain was still falling, and then our attention was called to the rainbow colours on a small cloud about five degrees from the Sun. It was now half a minute before totality, yet despite the fact that the Sun was still hidden behind clouds, we waited patiently for the eventful moment. What a farce it seemed! Astronomers keeping guard at the various telescopes under their charge, assistants ready to handle the photographic plates, five of us with white chalk in hand and sketching block, ready to make a drawing of the corona should it be our good fortune to gaze on the wondrous sight. Each one of the four was to draw a quadrant, and a fifth member of the party was to make a complete drawing of the corona. Later on the five drawings were compared, forming the material for a composite sketch. Meanwhile the rain was falling on our sketching blocks. The silence was broken only by the click, click of the metronome to be used during the

eclipse for marking off the precious seconds. It was now five seconds before totality—four, three, two, one; and then the miracle was accomplished. As though a hand had drawn aside a veil, the clouds parted, revealing next instant the dark globe of the Moon surrounded by the corona in all its glory, extending outward in starlike rays against the dark blue sky. Next to the dark rim of the Moon were a few rosy flames like a broken chain of rubies.

Only the voice of the one detailed to count aloud the seconds to the accompaniment of the metronome disturbed the otherwise absolute silence. An occasional exclamation was quickly suppressed. Swiftly our pencils endeavoured to portray those filmy outlines; but as the seconds glided into minutes, it seemed as though they mocked us with their speed. Thirty precious seconds were wasted, while a small cloud drifted across the eclipsed Sun, though so filmy that through it the outline of the corona could be clearly discerned. In that brief interval the writer caught a glimpse of Venus gleaming brightly against a purplish-blue sky, an oasis amid the vast expanse of cloud. Oh, for the gift of an artist's power in conveying the beauty of that scene, depicting the colour effect on the great masses of cloud within which the

Sun was framed, the deep orange tints low down on the horizon, and the wonders of a landscape scene baffling description.

But inexorable time was passing relentlessly on, and the cloud which had come so opportunely, giving one a chance to "view the landscape o'er," had drifted onward; and the work of drawing the corona must be resumed. All too quickly fled the three minutes and forty-five seconds of totality, and as the last second was called out despairing glances were cast at the corona as it faded gradually from view in the first flash of sunlight. At least so it appeared to the writer, who found that it remained visible for nearly fifteen seconds after totality.*

The darkness during totality seemed also much more marked, as compared with previous observations made by the writer in 1896 and in 1900, and it was with some difficulty that the white chalk drawing on the dark blue drawing paper, could be seen. Probably the clouds helped to intensify the darkness, and contribute to the greater gloom

*In *Eclipses of the Sun*, by S. A. Mitchell, on page 67, we read that "totality came ahead of its predicted time, the beginning of totality being seventeen seconds earlier, and the ending twenty-three seconds earlier, than the predicted time by the *American Ephemeris*." All observers at the Spanish eclipse had their program of observation greatly interfered with by having the Moon so far in advance of its predicted place.

overshadowing the landscape. As soon as the eclipse was over, a universal sound of cheerfulness pervaded the camp and we could hear the Cathedral bells in the distance ringing a merry peal as on a festival day. East, west, north, and south flashed the news of our success by cable all over the world, and in Burgos itself the rejoicing was general and there was a feeling of relief that the elaborate preparations which had been made by the various expeditions had proved worth while, after all.

Notes and drawings were compared, and telescopes and other apparatus carefully packed, before the observers returned to the city. As we walked slowly down the hill we met some of the peasants, who were still gazing at the Sun through pieces of smoked glass, as though in hope of another eclipse. Perhaps one of our photographers was responsible for the sale of smoked glasses which had been purchased for a peseta (shilling) apiece earlier in the morning. Having a number of broken negatives, he gave them to a native of the town, telling him how they might be sold to advantage that day. Keen to make a little money, the native showed the negatives duly smoked to an admiring throng, calling their attention to the fact that one of the greatest astronomers in the

world had looked through them and had guaranteed their value. Soon young and old procured some of the magic glasses, and a little girl, too busily intent on observing the Sun to notice where she was going, fell full length on the cobblestones and broke her glass to atoms. She was inconsolable until a kind-hearted professor witnessing her distress provided her with another. Then smiles replaced the tears and the amateur astronomer happily resumed her observation of the Sun.

Reports of Other Observations in Spain

Belated astronomers on their way to stations along the pathway of darkness in Spain had some difficulty, it is said, in reaching their destinations. For instance, late arrivals at Madrid, who were unable to secure accommodation in a train which was going to Siguenza, a small town within the pathway of totality, stationed themselves on the track standing in front of the engine, refusing to move until an extra carriage had been added to the train. Vast, bustling chattering crowds filled each station through which the train passed, especially in Akala and Guadalajara. During the twenty minutes the train was delayed at the latter station, it was absolutely besieged by venders of

"agua fria," biscuits and melons, at impossible prices, the latter, as some one expressed it, being "*mas altos que el eclipse*" and absolutely uneatable. When the train finally arrived at Siguenza, the astronomers literally had to push their way through the throng of curious peasants and eclipse enthusiasts. Then they hastened in search of an available site from which to view the eclipse of the Sun.

When the time for the eclipse drew nigh, great consternation was felt when clouds began to drift over the Sun, and raindrops fell, which the peasants said were the bitter tears shed by the Sun at being made captive by the Moon. Later on, however, the clouds drifted away, and the peasants applauded enthusiastically with delight. Gradually the light grew dim, and as the time approached for the moment of totality, a hush of expectant awe settled over the place. Faces looked ghastly in the waning light, flowers closed their petals as at night, and the leaves of the trees quivered as though shivering from cold. The birds could be heard twittering as they hastened to their nests, some fluttering down in the streets, allowing the peasants to pick them up in their hands. Chickens hastened to their coops, huddling against each other with ruffled plumage.

During the darkness of totality the awed silence of the watching populace deepened the effect of the gloom. The peasants gazed in rapt attention at the glorious sight overhead. It was a revelation to the simple folk, who crossed themselves and muttered a prayer, as though for protection against some unknown evil which had overtaken them. At the first gleam of returning sunlight they shouted for joy and clapped their hands like so many children. The eclipse was now over, the chilliness was replaced by warmth, and Nature resumed her normal aspect. A rush was made for the trains, which were filled once more to overflowing with a bustling, excited crowd, and Siguenza soon settled down into the usual calm of its everyday existence.

The eclipse station at Almanzan was occupied by the well-known scientist Camille Flammarion, who was accompanied by his wife; by Professor John Miller, of the Kirkwood Observatory, Indiana; and by members of an expedition from Mexico, under the directorship of D. Valentin Gama, subdirector of the Mexican National Astronomical Observatory of Tacubaya. The observations made at this station proved entirely satisfactory. No less than forty photographs of the different phases of the eclipse, the corona, and the coronal spec-

trum were obtained by the American astronomers. Dr. S. A. Mitchell gives an interesting account of the Naval Observatory expedition sent to Daroca in the heart of old Spain, about forty miles from Saragossa. The location of the eclipse camp was half a mile south of the town, in the midst of a beautiful fertile valley.

> "In such a valley along the shores of the little river was our eclipse camp located. The greenest field was decided upon as the site of the observatory, and upon application to its owner for permission, we found that he was quite satisfied to allow his plot of ground to be used, but thought some compensation should be made for the expected loss of the valuable crop of grass that might possibly have been raised during the summer. On receipt of one hundred pesetas, he forthwith proceeded to take a fatherly interest in all our doings, and explained scientific matters to everyone as if he had been chief of the expedition. His field became the centre of interest in the community, and people came from all sides to look upon the strange doings. As a prominent trait of the Spanish peasant seems to be a great and overpowering curi-

osity we had plenty of onlookers; and when the mayor and a few of the most prominent citizens were invited to look at the Moon through our five-inch telescope, we were rather surprised—to put it mildly—to find over one hundred people turn up, when only half a score had been invited. Their curiosity took the form of making each and every one in the town intensely interested in what was going on, and to show their interest they turned out in force each afternoon to see how matters were progressing.

"At 11.52 A.M. (on the day of the solar eclipse) a little indentation was seen on the western limb of the Sun, and the eclipse had begun. The skies were clear with the exception of a cloud here and there and our most ardent wish was that the clouds would leave the Sun clear for the next couple of hours. For the first hour that the Moon was creeping over the Sun there was nothing of very great moment to notice, but for the next twenty minutes until 1.12, when the Sun was blotted out, we were each of us filled with expectancy, for matters began to take on a weird and unnatural appearance. The little blotches of light under the trees, instead of being fa-

miliar circles, were little crescents, exact counterparts of the sun itself. The darkness began to make itself really felt, and without looking at the Sun one would know that something out of the ordinary was happening, for the gloom did not in the least resemble that of sunset. A hush fell upon the crowd of assembled and talkative Spaniards when, ten minutes before totality, a big cloud drifted over the Sun. Would this cloud move away? Or were we going to be disappointed? It hung there for a space of time that seemed to be an age, while in reality it lasted only five minutes, but when it passed there was a shout from us all. Seventeen seconds before the calculated time, with the last disappearing ray of sunlight, the corona broke forth into view. What a magnificent sight it was shining out with its pale, pearly light for a couple of diameters round the edge of the Sun, with its streamers and brushes of delicate light!

"True to prediction, the corona was almost square in shape. . . . In the upper left-hand quadrant huge red flames 60,000 miles high could be seen with the naked eye, and these with a closer view with the telescope resolved

themselves into a forest-like structure. Close to the Sun the corona was very bright, in fact so brilliant that the eye could not readily take in all the details of the faint streamers. It was a magnificent sight, and we were more than thankful for having clear skies for making our observations.*

"All that was heard in the eclipse camp was the steady count of the observer calling out the seconds as they passed, the quiet words of the observers giving commands to their assistants, and the click, click of the various pieces of apparatus as exposures were made and plate holders removed. Everything passed off without a hitch, and with the first reappearance of the Sun our work was over and we could take a long breath. We had been favoured with clear skies. How many others were equally fortunate?

"It did not take us long to find out, for the Spanish government had installed right in our camp a telegraph office, and for fifteen days no less than three operators were at our service to send and receive our messages. . . . The weather along the eclipse track was: in Labrador, cloudy (no observations made); in

*_Eclipses of the Sun_, pp. 191-192. S. A. Mitchell.

Spain, cloudy and clear; in the islands of the Mediterranean, mostly cloudy; on the coast of Africa, slightly cloudy; but further inland and along the rest of the eclipse track the skies were perfect. All three parties of the Naval Observatory were fortunate in having their work unhindered by a single cloud." *

At Palma, Majorca, the expedition from the Solar Physics Observatory, under the direction of Sir Norman Lockyer, and assisted by the officers and crew of H.M.S. *Venus*, proved unsuccessful, for as the moment of totality arrived dense clouds came up and hid the Sun. Sir Norman Lockyer had originally intended to make his observations of the eclipse at a station near Philippeville in Algeria, but for some reason was not permitted to do so by the government. This was especially unfortunate, as clear skies prevailed in this region and success would have been assured.

Elsewhere at Palma, the sky was clear and good results were obtained. According to the account given by Dr. A. C. De la Crommelin, the beginning of totality was observed by watching the disappearing solar crescent projected on a screen behind the eyepiece of his telescope. Baily's Beads

* *Eclipses of the Sun*, p. 193. S. A. Mitchell.

were very well shown by this method, and formed a beautiful spectacle. During totality he took two photographs with a portrait lens, showing clearly the prominences and the inner corona, also the bases of the principal streamers, but very little extension of these, owing to obscuration by thin cloud. During the remainder of totality he observed the corona through an excellent binocular. "The prominences and inner corona were exceedingly brilliant," to quote his own account, "the latter to my eyes appearing of a bluish white, so bright that I could quite understand how Kepler took it for a part of the Sun, and imagined that the Sun could never be totally eclipsed. The unusual brilliance of the corona is further established by the fact that Mr. Hodges (a member of the expedition) saw the Moon's limb plainly projected against it quite 1° outside the Sun about thirty-five minutes before totality. There was far more light than I expected during totality, and the small figures of a watch and thermometer were easily visible. This differs from the experience of observers at other stations; perhaps the fact that we were a long way north of the central line had something to do with it."

Other interesting reports of observations made by members of the British Astronomical Associa-

tion of the total eclipse of 1905, August 30, have been incorporated in book form, and they show the varied experiences obtained at different places along the line of totality. From some stations came reports of "*todo malo tiempo*," and at Roquetas, a town in Tortosa, the sky was cloudless at dawn, but, alas! at the moment before totality the Sun was absolutely hidden from view by a thick bank of cloud, with only occasional glimpses of the corona for a second or so at intervals, and a momentary view of a large red prominence. Yet an inhabitant of Tortosa had assured us of cloudless skies at this season!

The Eclipse as Seen from the S. S. "Arcadia"

Several attempts were made by members of the British Astronomical Association to arrange an expedition by sea, so as to avoid a train journey across France and Spain during the hot days of August. Negotiations were entered into in connection with the Pacific and Orient steamer *Arcadia*, leaving Tilbury on August 25. It was due to cross the central line of the eclipse on the very day of the eclipse and almost at the hour of totality. Arrangements were made that the ship should heave to for two or three hours to enable passengers to

have a leisurely view of the eclipse. This decision was communicated to the members of the B.A.A. and others, who had expressed a desire to see the eclipse, and the "station taken by the ship was only a short distance from the Colombretes Islands off the coast of Spain." The *Arcadia* party was under the direction of Mr. G. F. Chambers, F.R.A.S., who arranged a program including observations of the shadow bands, solar flames, "Baily's Beads," and making sketches of the corona. These were made with white chalk on blue paper, and a comparison of drawings later on showed a general agreement as to the outline of the corona, its brightness and colour. Only one conspicious ray was delineated, stretching out from the corona, together with four or five minor rays, none of them very noticeable. The solar flames outlined against the inner corona were much paler than usual and the elusive shadow bands were seen, though not as very conspicuous objects. "Baily's Beads" were observed by some, but not by all who made a special point of looking for them. Reference has been made elsewhere to these appearances at the time of a total eclipse of the Sun, and according to one observer they have been described as "golden balls resembling a string of brilliants, which appear for a few seconds before

totality on the edge of the Moon, and suddenly disappear like drops of water drying up under a hot Sun." It has been suggested that "Baily's Beads" may be due to irregularities upon the surface of the Moon at its edge or limb, the lunar mountains projected against the bright solar crescent causing divisions in its light.

A very successful observation of the approaching shadow was made by Mr. Bacon, first officer of the *Arcadia*. He was hauled up in a basket to the masthead, and from that lofty position was enabled to see the approach of the shadow cast by the Moon as it rushed between the Sun and the Earth. He not only saw it approach, but recede, a double observation rarely made but often attempted. Preparations made to observe stars visible during totality failed, owing to the interposition of clouds, only Regulus and planet Venus being visible.

The extreme blackness of the Moon emphasised by the dazzling white of the inner corona outlined against the sky was a colour effect which attracted considerable attention, and some of the observers reported seeing the whole contour of the Moon projected on the sky, immediately after first contact. The breeze which generally springs up at the time of totality appeared as usual, with the

novel and interesting addition, that according to the testimony of one of the ship's officers, "the wind suddenly veered through eight points of the compass." Observations were made of the ever-changing crescent of light observed at various stages of the eclipse, projected on the deck of the *Arcadia* through the eyelet holes of the canvas awnings.

The director of this special eclipse party—*viz.*, Mr. G. F. Chambers, F.R.A.S.—had provided himself with a very good 2¼-inch refractor, mounted as an altazimuth on a tripod stand, armed with a power of 20, and a diagonal eyepiece. To quote his own words:

> "For this I received no encouragement from my friends, most of whom jeered at the idea of the possibility of using on ship-board a telescope mounted on a rigid stand. I was not very sanguine myself, but when the time arrived I was able to use the telescope so mounted with perfect success. Thanks to the calmness of the sea, and the skill with which Captain Cubitt, R.N.R., handled his ship, my telescope was practically motionless throughout the eclipse, except when I found it necessary to give it a push in order to fol-

low the moving Sun. We all felt that we owed a great debt of gratitude to Captain Cubitt for the many facilities of various kinds that he gave us for the successful performance of our work."

Eclipse as Seen from the S.S. "Ortona"

The following observations were made on the Orient steamer *Ortona*, by Mr. S. L. Walkden. The ship was situated on the central line of the eclipse in the Mediterranean near the coast of Spain. Mr. Walkden saw the rainbow colours visible on a small cloud near the Sun about a minute before totality. Although he looked for the onrushing shadow, it was not seen, nor the shadow bands before totality, though he observed them on deck, at the end of totality. They rippled onward a little faster than could be easily followed by the eye of the observer, and were parallel to the strip of the Sun after totality, moving in the direction of the shadow. They resembled dark strips about six to eight inches wide, separated by a distance of about eighteen inches.

A minute before totality, Venus was seen, and Regulus, the brightest star in the constellation Leo became visible during totality. The corona was

CHART SHOWING ECLIPSE TRACK, MAY 11, 1724

very fine and full of detail, the coronal streamers crossing each other, while others were distributed in stellate form round the Sun. One streamer extended to a distance equal to about two diameters of the Sun.

> "The lightness of the eclipse was very marked, and time by the watch was always plainly visible. The sky illumination was greatest near the horizon, presenting a yellow glow as at sunset, in points opposite to the Sun (about north point). Coast lights were visible a few miles away, and one hill to the north appeared as if perforated, with the sky showing through. This was observed by one of the passengers. Venus remained visible nearly five minutes after the end of totality." *

*Abstract from *Nature*, September 7, 1905.

CHAPTER X

DESCRIPTION OF THE TOTAL ECLIPSE OF THE SUN, JUNE 29, 1927.

THE total eclipse of the Sun of June 29, 1927, which attracted so much popular attention as well as that of the scientific world, was greatly enhanced in importance by the fact, that it was the first to occur in England since 1724, and that there will not be another until 1999. Shortly after sunrise the eclipse became visible for dwellers along a track leading from Anglesea, through Southport, across York and onward to West Hartlepool in Northumberland, passing thence through Norway, round by Nova Zembla, and finishing at sunset beyond the Behring Straits. On each side of the track within which the eclipse was total, (on this occasion only 30 miles in width), the same eclipse was visible as a partial one everywhere within two thousand miles. For instance, it was partial at Greenwich, Cambridge and Oxford to the south of the line, and at Glasgow and Edinburgh to the north.

The eclipse lasted from twenty-two seconds to twenty-four seconds according to the site selected by the observer within the shadow track in the British Isles, therefore it was essential that one should decide definitely on how that brief interval might be used to the best advantage. The outstanding feature of the eclipse was a curious phenomenon which has never before been recorded in the annals of telescopic observations of solar eclipses. As it happened the Moon was not near enough to the Earth to hide the Sun entirely from view, but left exposed a part of the chromosphere —an ocean of scarlet flame, presenting the appearance of a circle of red light surrounding the Moon's disc. Thus, during the total eclipse of the Sun, it was possible to see the dark globe of the Moon, encircled with a rim of red forming a marked contrast to the dazzling white of the inner corona, and the silvery streamers or rays of the outer corona beyond.

According to a paper contributed to the December Meeting of the R.A.S. in 1871, by Professor R. Grant: "Since the apparent diameter of the Moon sometimes exceeds, sometimes equals, and sometimes falls short of the apparent diameter of the Sun, it is obviously possible that the existence of such an envelope (the chromosphere) may be

revealed by the phenomenon of a circle of red light surrounding the Moon's disc during a slightly total eclipse of the Sun. No instance, however, of such an occurrence has been recorded in the annals of telescopic observations of solar eclipses."

Those who were merely intent on observing the eclipse from the picturesque standpoint had a fine opportunity for seeing the approach of the Moon's shadow by selecting a site from which they could have a view commanding the western horizon. As already stated, in a former chapter, in higher latitudes where the velocity of the Earth's rotation is less, and the relative speed of the shadow is higher, its approach may become exceedingly swift—as great as 4,000 or 5,000 miles per hour. It is seen advancing with terrifying speed, seemingly overwhelming the observer at the time of totality. Then out flashes the corona in all its splendour and all too swiftly will the brief instant of totality come to an end, followed instantly by the disappearance of the corona, maybe the first and only view for many of the observers in their lifetime.

The most favourable position for observing the approaching shadow at the solar eclipse in 1927, was from an aeroplane or the summit of a mountain such as Snowdon in Wales, or a lofty,

peak in Norway, and there were many situated within the track of shadow. (Incidentally, the total eclipse lasted about fifty seconds in Norway.) It is true the eclipse occurred at an early hour in the morning, necessitating climbing the day before, camping out all night—(though a summer night in June in Norway can scarcely be called night), and the possibility of the mountain heights being enshrouded in mist at an early hour. Nevertheless, the following account given by Jas. Backhouse, Jr., regarding his view of a total eclipse of the sun would appeal strongly to the imagination of a sturdy well-equipped mountaineer:—

"On June 28, 1851, unattended by any companion or guide, we (J. B. Senior and myself) ascended Sulu Tind, the highest peak of that part of the great central chain of Norwegian mountains known by the name of the Fille Fjeld. At an elevation of nearly 6,000 feet and surrounded on every side by snowy mountains and barren rocks, we waited in anxious hopes that the heavy clouds would disperse, and permit us to see the Sun, whose beams were illuminating vast fields of snow, at no great distance. The morning had been by no means promising, the higher mountains being all enveloped in mist, while black and stormy clouds sailed in rapid succession up the

glens. We had almost feared to climb to the top of the mountain, knowing that if the dense covering did not lift, not only should we be unable to see the Sun at the time of eclipse, but that we should also miss the effect of the obscuration on the surrounding landscape.

"However, determined that nothing should be wanting on our part, to secure a scene never again to be beheld from so favoured a position, we steadily pressed upwards through all interposing difficulties, soon leaving the dark glen of the Lierdal's Elv far beneath us. Occasionally a bright beam of sunshine burst through a transient opening in the clouds, raising the temperature of our hopes, and animating everything with its genial warmth. At length the summit was gained, and gradually the fleecy clouds, encircling the precipices, gently rose, leaving an atmosphere of crystalline clearness, and a prospect of extreme grandeur in every direction. Vast tracts of snow covered the great plateau of the Fjeld, 1,500 or 2,000 feet beneath us, from which streams and rivers started into existence, and poured their foaming waters into the distant glens below.

"In front, the dark crags of the Odde Berg stood before us, and far beyond, the snowy Jokulen reared its dome of spotless white on the

western horizon. To the east also, ranges of snowy mountains rose one over the other, till lost in extreme distance, while frozen lakes of varied form lay half buried in the hollows amongst them. Yet far exceeding all these in grandeur, were the spiked and dome-like peaks of the Hurungerne, forming part of the loftiest chain of the Norwegian mountains, which reared their giant precipices to the northward, barred and seamed with glaciers, far above the dark wreaths of cloud which still clustered round them, as if unwilling to resign their resting place. Such was our enviable position when the eclipse began.

"It was not till a large portion of the Sun was obscured that we could perceive any visible change in the intensity of the light. Gradually the glow gave way to a pale and rather sickly glare, as though the combined rays of the Sun and Moon shone upon the landscape. In a few minutes the light decreased so rapidly that we could perceive its diminution every second; a dull red tinge spread for a moment over the distant mountains, and then a transient scene of unparalleled grandeur commenced. The sun itself was obscured by an intervening cloud, so that our undivided attention was concentrated on the magical effect of the total obscuration on the landscape.

"First, a curtain of intense leaden darkness, definite in outline, though shaded at the margin, utterly obliterated the snowy range of the Jostedal, at the north of the Sogne Fjord, more than fifty miles distant, whilst all the nearer landscape glittered in a lurid sunshine. Then a stream of dull red tinged the northern horizon, which rapidly assumed a glow far more imposing than any sunset. It was a "sunset," not produced by the Sun on the horizon, and at its lowest power, but in the full resplendence of meridian day! an effect never to be witnessed save under the magic influence of a total solar eclipse. As the veil of night approached us, extinguishing first one snowy peak and then another, till the whole was buried in a visible darkness, this sunset glow, now a brilliant copper orange, suddenly shot over the whole northern and eastern horizon, in front of which the sharp peaks of the Hurungerne towered with jetty blackness into the clouds. This extraordinary effect was produced by our being so near to the centre of the shadow, that for many miles around us in every direction the eclipse was total; while, from the great elevation, we could see beyond the region darkened by the umbra of the eclipse, to the distant horizon which was only partially obscured.

"Floating in the sea of orange, were little clouds of intense crimson-purple, each distinctly margined with a band of brilliancy like frozen lightning! In about two minutes the deep sunset hues gave way to all the exquisite tints of sunrise, every particle of orange having passed out of the scene, and replaced with marvellous rapidity by the loveliest shades of rose and carmine.

"Soon the snowy Fjelds were again illuminated and the night of darkness left the gloomy glen below us, slowly retreating like a vast curtain over the mountain ranges to the south and west. Long after the day had again risen on the Fille Fjeld with all its brightness and beauty, we could look into the region of night still lingering in the distance. The darkness of the eclipse was not the blackness of a moonless winter's night, but a deep leaden indigo colour, just sufficiently transparent to permit of objects being dimly visible. At the time of the greatest obscuration, the snow that we were standing upon lost its whiteness, and was invisible except in our immediate vicinity.

"The temperature fell from 45° to 42° (Fahr.), and masses of cloud previously sailing around and above us, vanished on every hand, leaving even the spiked top of the surpassing Skagastolstind perfectly clear. Some faint idea of the scene may

be realized by imagining an ordinary day, sunset, night, sunrise, and again day, all crowded into the space of five or six minutes, and beheld from an isolated mountain nearly 6,000 feet high, with a range of view 150 miles across! When the darkness approached and the first play of sunset colours appeared, the rapidity of the change drew from us constant expressions of wondering delight; but as the obscuration became total, the effect was too overwhelming, and in perfect silence we *felt* the awful solemnity of the scene. It seemed almost as though the world had vanished, or been reduced to the mere crest of rocks on which we stood, the gloomy horizon before us, and black intervening mountains looking as though they scarcely belonged to our planet."

After reading such a picturesque description of the scene, many were tempted, at the recent eclipse to scale the heights of Snowdon but were not rewarded for their trouble. A great curtain of mist, cloud, and driving rain hung over the mountain on the morning of June 29, 1927, completely veiling the magic splendour of the corona. Many women and children, who had climbed all night, peered in vain, at dawn, through the impenetrable gloom, hoping to obtain at least a glimpse of the corona. Although Snowdon was almost on the central line

of the shadow belt, all that the watchers could see, was the changing colour of the mist from a light grey to a shade of deep mauve. Cold and disappointed they sought shelter in the two wooden huts on the summit of the mountain.

No official expedition had been arranged by the Joint Permanent Eclipse Committee of the Royal Astronomical Society, but the following parties were organised, which met with more or less success. A party from the Royal Observatory, at Greenwich, organised by Sir Frank Dyson, the Astronomer Royal, which was stationed at Giggleswick, Yorkshire, where splendid results were obtained. One at Hartlepool organised by Dr. Lockyer and Sir Frank McClean, which unfortunately proved a failure owing to cloudy skies. A party at Southport, organised by Professor H. H. Turner and Dr. H. Knox-Shaw, which met with success. A party at Stonyhurst under Father O'Connor, which was fairly successful, a small cloud obscuring the Sun, leaving only a fragment of the corona visible, at the critical moment. An expedition to Aäl, in Norway, under Professor Newall, Director of the Cambridge Observatory, which met with failure owing to clouds hiding the corona from view.

Naturally, the expedition which excited the

keenest interest was that under the direction of the Astronomer Royal, of which the following account was given by the special correspondent of *The Times*.

GIGGLESWICK, JUNE 29.

The eclipse of the Sun was visible from the Astronomer Royal's camp at Giggleswick during the whole period of totality. Satisfactory observations were made by the scientists, and many thousands of people saw an astounding and thrilling spectacle. News which came later, that at other places on the line of totality in the country and on the North Sea little or nothing had been seen of the eclipse, caused thousands here to marvel at their good fortune.

Five minutes before the Moon's shadow swept over the hills, the Sun reduced to a thin but dazzling sickle, passed finally out of a bank of cloud into a limited but sufficient clearing in the sky. A curious melancholy light fell upon the fields. Slowly at first, and then with amazing rapidity, it faded out, and for the space of 23 seconds the Sun became a black globe, surrounded by the brilliant flames of the unforgettable corona. Quite soon after totality the cloud curtain closed again, but we had been allowed our vision. The luck of the camp was the more remarkable as from

Buckhaw Brow, only a short distance away, the total eclipse was not in view. Until the spectrographs exposures have been developed and studied at Greenwich Sir Frank Dyson cannot estimate the value of the results obtained by his staff, and for the moment the eclipse must be described as a pageant and an emotional experience.

The weather, which at sunset yesterday had brightened after days of rain and lowering skies, continued to improve during the night. There was no breeze at dawn, and the branches of trees which had rocked before the wind 12 hours earlier were still. As the light strengthened it could be seen that the clouds were broken and comparatively thin, except in the east, where they remained grey and heavy. The Astronomer Royal reached the camp at 4 o'clock, and said there was a growing possibility that they would be able to "get something." He talked cheerfully with his assistants, and walked round to inspect the instruments. About a quarter to 5 A.M. a patch of cloud above the Pennine ridges turned rose pink, and by its flushing announced the risen but hidden Sun. In the school grounds a gathering which included Mr. Ramsay MacDonald silently and anxiously watched to see if the stain would spread. They saw the cloud turn grey again. Overhead there

was a fair expanse of blue sky, but the bank beyond the hills remained a tantalizing barrier.

At 5.29 A.M. the eclipse began behind a veil. Fifteen minutes later a patch of gold shot across the cloud, and at 5.47 A.M. the rim of the Sun, showing for a few seconds, stirred the astronomers to eager activity. Before they could operate the coelostat the gleam had passed, but sufficient had been seen for even non-technical observers to realize that a possibility of the Sun getting above the cloud had become a definite probability. A two minutes' appearance just before 6 A.M. was encouraging and useful. The race grew in excitement, but at 6.8 A.M. it seemed to be won. The Sun came fully out, and stayed so for nine minutes. Excellent observation of the all-but-covered disc was obtained, and the last adjustments were made to the mirrors. Another tongue of cloud passed, but there was enough clear sky beyond to ensure visibility during the critical seconds.

A ten minutes' warning had been given by Mr. Horrocks, the young Isaac Newton student in the University of Cambridge, who had charge of the timing, and as the Sun emerged for the last time that mattered he called in a loud, clear voice, which reached all the observers, official and unofficial, within the camp, the words, "Five

minutes." Many who knew that the precious opportunity was to be given them of seeing the corona turned their backs on the east so that with unshaded eyes they could swing round at the moment of totality. They saw in the west a leaden sky like to that which might precede a thunderstorm. Birds which had been twittering musically seemed to be disturbed, and rose and circled without purpose. A group of sheep in an adjoining field huddled themselves together against a wall. The air grew chilly. A voice called, "Two minutes." The light was weird and mysterious. Nerves were on edge. Day seemed to be rushing into night. "One minute," the timekeeper cried, and then "Fifty."

All that had gone before seemed insignificant in the amazing moments that followed. The sinister yellowish twilight faded away as though some unseen hand were turning off a gas-jet. The shadow rushed at us and enveloped us. We turned and found the Sun blotted out in a sky akin to that of a full Moon. To the extent of another diameter the disc was surrounded by a glowing, iridescent, irregular circle of fiery light from which shot red and yellow flames. The spectacle surpassed anything that imagination had shaped for

the eclipse. Half consciously one heard Mr. Horrocks counting seconds while mind and vision were concentrated on the glory of the corona. As "Twenty-three" was called a dazzling flash of reddish-white light, brilliant as that of molten steel run from a crucible, burst out from the right upper rim of the darkened Sun. Watched by the naked eye, the flash appeared to bulge into a blazing oval. Suddenly there came realization that the darkness was passing, that the corona had vanished, that the Moon's black disc on the Sun could no longer be seen. From somewhere behind the camp came a sound of cheering. The eclipse was over, or as much of it as anyone now wished to see. Looking at a white sickle through a plate of smoked glass was only mildly interesting. Birds recovered their desire of song, the gathered sheep began to separate, and from the hillside the crowds moved slowly to the highways.

Reports from all parts of the totality belt in Norway show that the eclipse was almost entirely invisible owing to bad weather conditions in the central districts where most elaborate preparations had been made. Dr. S. A. Mitchell, Director of Leander McCormick Observatory, University of Virginia, U. S. A., was stationed at Fagerness.

He saw fitful gleams of sunlight, but at the moment of totality, the sky was entirely overcast. Further north, however, the weather conditions were perfect, and excellent observations were made, as well as photographs taken by Norwegian and German scientists.

Professor Newall, Director of the Cambridge Observatory, who was stationed at Aäl, in Hallingdal, reported that observations of the eclipse were "entirely frustrated by clouds."

During the meeting of the British Association which met at Oxford during the month of August, 1926, Professor H. H. Turner urged that as many girls and boys as possible should be given an opportunity for seeing the eclipse, to which a ready response was made. Hundreds of children were taken by means of special trains to places along the shadow track, though unfortunately owing to weather conditions, only a favored few had a glimpse of the corona. Among the most interested spectators at Southport, were the one hundred boys who had been sent free of expense owing to the generosity of the *Daily News*, which had organised the expedition.

Moreover, the *Daily Mail* distinguished itself by placing an aeroplane at the disposal of the Astronomer Royal, so that photographs of the

corona might be obtained, should clouds obscure the sky at Giggleswick, the site selected by the Royal Observatory expedition. Fortunately, for the cause of science, Giggleswick was the most favoured site along the shadow track. Consequently, photographs were successfully obtained not only on land, but in the air as well, owing to the help given by Imperial Airways Ltd., and the skilful guiding of the aeroplane by Captain Barnard. (Sad to relate he was killed in an air crash, only a month later.)

In one of the photographs taken by Mr. Witchell, one of the Greenwich observers who went in the aeroplane, the leading features of the inner corona were conspicuous, and several prominences, as well as much of the outer corona. A photograph taken near the end of totality showed the Sun emerging in one part while quite a perceptible piece of the corona was visible in another part.

Mr. Hargreaves, another Greenwich observer in the aeroplane, in reply to queries regarding the eclipse, remarked:

"It was a sight I cannot describe adequately. I have made a drawing from the photographs taken by Mr. Greaves and Mr. Witchell which, though quickly done, at least shows that from the aeroplane observations alone we could have given a

very good general outline of the corona." He also obtained a picture of the onrushing shadow—the only one taken in England. Dr. Morehouse, of Des Moines College, Iowa, obtained a very good view of the eclipse at Southport, as well as Professor Caroline Furness, of Vassar College, Poughkeepsie, New York State. She commented on the fact that while observers in the *Daily Mail* aeroplane had described the prominences as white, those on the ground had seen them as red. She suggested that this difference should be investigated. In spite of favourable conditions at one of the American eclipses, she remarked, that no photograph comparable in detail with that secured at Giggleswick had been taken.

The following is a vivid description written by a special representative of the *Daily Chronicle*, describing his view of the eclipse as seen from the *Daily Chronicle* aeroplane, which ascended to a height of ten thousand feet:

I determined to improve my chance of seeing the eclipse by taking an aeroplane. I left the city at a quarter past five on Tuesday evening, and an hour later four of us flew from Croydon Aerodrome in a four-seater De Havilland 50 in charge of one of the best pilots of the Imperial Airways.

We headed for Catterick, which is about 250 miles due north, near Richmond in Yorkshire.

A few minutes after leaving Croydon we circled once round the centre court at Wimbledon, where two feminine figures in white were batting from the base-line a thousand feet below us.

Then on to Rugby, where the enormous wireless masts at Hillmorton came into sight. We flew level with the top of the 820 ft. masts and, making a half-circle round the wireless station, we made steady progress to Catterick.

A Mecca of Motorists

We landed at 9 o'clock, and were followed shortly by the large double-engined aeroplane carrying a Greenwich Observatory party.

After a conference with the pilot on the plans for the morning, I motored 12 miles to Northallerton and got to bed at 11 o'clock. The short night's rest was disturbed by streams of motor traffic and the constant passing of trains. All the world seemed to be pouring into the area of totality.

I was called at 4 o'clock and was on the aerodrome at ten minutes to 5. In the last two miles to the aerodrome, which it must be remembered

was within the area of totality, there was a constant stream of motor traffic, reminiscent of Derby Day. The aerodrome itself was alive with machines. Besides our own and the Astronomer Royal's machine there was a Vickers-Virginia bombing machine and one or two other Air Force aeroplanes and half a dozen D. H. Moths.

At this hour of the morning the sky was overcast with thick grey clouds, which seemed to be about 4,000 feet up. Through gaps we could see occasional patches of blue sky.

One thing was clear: our day was to be a battle with the clouds. We must fight our way up and through them until we could find a clear view of the Sun. No time was to be lost, for to climb 10,000 feet or more, which might well be necessary, would take us an hour.

At ten minutes past 5, discarding all luggage and everything but two cameras and some field glasses, we climbed into the sky.

It was as though the high heavens resented the publicity of this modern eclipse. Battalions of clouds had been massed to defeat the armies of motor-cars and express trains.

As we rose we fought first with fast moving clouds that seemed hardly more than a thin mist

when we got into them. We could still see the ground beneath us, looking grey and rather dismal.

Then, as we went up into the heavy masses of cumulus clouds, it seemed that we were meeting the heavy artillery of our opposition. We climbed and climbed and still the clouds were round us in rolling, billowing masses.

We raced through gorges in clouds, but still they hid the Sun.

It was not until we had climbed well over 5,000 feet, which we reached soon after 5.30, that we got our first real glimpse of the Sun and almost at that moment the eclipse had begun.

As I looked through darkened glasses I could see the first contact of the moon's "limb" on the Sun. In the rifleman's lingo, the Moon had scored an outer at two o'clock on its target.

We must still climb, for when the moment of the eclipse came we wanted to shut off our engine so that the vibrations of the motor might not affect the cameras. We must have ample room to manœuvre even while losing height.

Just then I caught sight of the Astronomer Royal's machine breaking through the clouds. It had left the ground a few minutes after us with a party from the Greenwich Observatory.

Now the sight became one of great impressive-

ness and great isolation. Somehow that single other aeroplane flying with us above a complete carpet of grey billowing waves made one feel as though in another world.

And what a bitterly cold world.

We had taken the top off our aeroplane in order to get a better view, and had now encountered a strong wind at 10,000 feet.

By 6.10 we felt that we had beaten the clouds, when we suddenly realised a new danger. The high cirrus clouds were threatening to cover the Sun if we maintained our course along the centre line of totality towards the sea.

There were now three problems to consider—we must change course in order to manœuvre the Sun clear of the cirrus clouds. We must be able to keep our aeroplane, at any rate during the final moments of the eclipse, at a prearranged angle, in order to give us the best outlook for the cameras and, above all, we must avoid leaving the area of totality. This is most difficult when you are flying at 100 miles an hour with thick clouds between you and the ground and with a strong cross-wind to carry one out of the 30-mile belt of totality.

A further scientific refinement had to be borne in mind. Approximately every 3,000 feet of alti-

tude displaced the whole zone one mile south, so that our northern boundary was three miles nearer.

In fact, our battle with the clouds went on until the last moment.

Below us the masses of cumulus were now taking on strange and rather terrifying colours. The Sun's disc seen through lightly tinted glasses was reduced to a slender crescent.

Its light was momentarily becoming weaker, and, as it dimmed, the light it cast on the clouds changed from an ochre-ish green into the darker shades of mauve and purple.

In a last effort to clear our view of the Sun of all obstruction from the cirrus clouds the pilot swung the aeroplane so that I got a view out behind instead of in front.

Then the Moon finally snuffed out the Sun—one great circle of black with a luminous fringe, and we got the wonderful impression of the speed of the Moon's passage through space as its shadow raced across the clouds below us.

The Moon's triumph, as we saw it, was fleeting, for we had flown so near our boundary that the period of complete totality for us was reduced to about two seconds.

The effect of the cirrus clouds near the Sun also

reduced the total optical effect of the eclipse, for the most perfect conditions are those when a clear sky becomes an inky black background to the corona; but, even so, there could clearly be seen a serrated fringe of light extending to a short distance, though whether this effect was real or due to the slight haze of cirrus we could not be sure.

"Baily's Beads," a curious effect as of drops of red bridging the last wisp of crescent, could also be seen, and there was very marked flickering in the Sun's light for several seconds prior to totality.

At the critical moment the pilot shut off his engine, and we obtained one photograph which clearly shows the apparent striation in the corona in the immediate proximity of the Sun.

And now I signalled the pilot to turn the plane downwards and make for Catterick. As we came out through the clouds the rise in temperature was most marked, but we found that we had lost our way while manœuvring above the clouds. We headed due east until we made the coast, and then found ourselves above Middlesborough.

Turning south along the coast, we reached Hull, and then bore due west back to Catterick, where we landed at 8.20. We found the Greenwich party already returned, and were glad to learn

they had been successful in catching the Sun in a perfectly clear patch of sky.

A quick breakfast and a fresh supply of petrol, and we left again at 9 o'clock for Croydon. We flew southwards in company with their machine, of which we took several photographs, and arrived without incident at Croydon at noon.

The following is another thrilling account of a view of the total eclipse of the Sun, on June 29, as seen from an aeroplane. It is given by Captain Paul Bewsher, D. S. C., a member of the staff of the *Daily Mail*, and a distinguished night-bomber in the War, and is written from the spectacular standpoint.

"In the vast emptiness of the sky, high above a boundless sea of clouds, I have just witnessed what must be the most amazing and terrifying spectacle ever seen by a human being.

"I have seen in one minute the universe to which I have been accustomed all my life changed to a fantastic nightmare.

"I have seen a deep, unearthly twilight fall in a few seconds out of a sunny blue sky.

"I have seen a glowing yellow sunset leap up, in a flash, behind a swiftly darkening landscape of blue and yellow clouds.

"I have seen the blazing Sun give place in one

AEROPLANE PHOTOGRAPH OF ECLIPSE, TAKEN JUST BEFORE TOTAL ECLIPSE OF THE SUN, ON JUNE 29, 1927, BY *Daily Sketch* REPRESENTATIVE

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moment to a black disc, fringed with feathers of cold white flame hung in the chill dark blue of the sky like a monstrous symbol.

"In a sky of a strange, deep, slatey blue—which had neither the darkness of night nor dawn nor dusk, but an unforgettable frightening darkness of its own, a crystal-clear almost luminous darkness—hung the black ball of the moon with its wide halo of wispy silver light in which at two places blazed a dazzling spot of fire, like liquid drops of white-hot metal.

"Below, in a ghastly gloom, lay the leagues of castled clouds with their distant peaks standing stark against the queer glow of yellow light on the horizon.

"One could almost imagine that a low wall swept across the countless hills and valleys of this dim cloud world beneath the monstrosity in the sky. It was as though one had been transported in a second to a cold, dead lunar landscape at deep twilight.

"Suddenly from the right side of the corona burst a dazzling sickle of intense white light. The total eclipse was ended. For a few moments the black disc of the Moon rimmed with a line of light could still be seen to the left of this flaming crescent. It passed away, and swiftly the wholesome

golden light of the Sun swept again over the weird, unhealthy greenish horror of the cloudland far below me.

"So much menace, so strong an impression of impending doom, had there been in the gathering darkness and the dread moments of totality, that when the sweet day returned one felt as if the sudden ending of the world had been set in progress and had been stopped at a critical moment.

"I was the only person out of the six in the machine who was able to watch the total eclipse as a spectacle."

The following, written especially for the *Daily Telegraph*, is my own account of the total eclipse of the Sun as seen from an aeroplane, though it is maybe an anti-climax to the descriptions already given. The account was written within a few hours of the experience, and I have left it as my actual impressions jotted down while en route to the aerodrome, on the aeroplane, and on my way homeward:

As the time drew near for the total eclipse of yesterday, I found it extremely difficult to make up my mind as to the best site within the shadow track from which to observe the corona. In fact, after hearing all the discouraging reports regarding various localities, which at first seemed so

promising, I finally made up my mind not to run any risks as far as seeing the corona was concerned, but to make sure of once more enjoying this wondrous sight by going up in an aeroplane, and seeing it above the clouds, should necessity require.

We left Croydon Aerodrome for Chester on Tuesday at 5.30 p. m., and the 'plane stopped overnight at Seafield Aerodrome. We left there for the shadow track at 5.45 a. m. As we stood at the door of the hotel, awaiting the taxis which were to take us to the aerodrome, we saw hundreds of boys and girls on their way to the station, for arrangements had been made for them to see the eclipse from Rhyl. As soon as we arrived at the aerodrome we took our place in the 'plane and started for the eclipse track. The prospects were not encouraging, as the Sun was hidden behind the clouds, except for occasional glimpses obtained through openings. We saw aeroplanes large and small on their way to different points along the route, but from all reports, even climbing upward above the clouds did not seem to improve matters, as the Sun was only about eleven or twelve degrees above the horizon.

Realising that our chances of seeing the corona were slim, I concentrated on observing the changing appearance of the landscape, which became

noticeable about six o'clock. The distant mountains in the west were outlined in a soft misty haze, though the landscape beneath us seemed little changed in appearance. Gradually the haze of the mountains blended with a blue tinge, merging into the greens of distant fields, and the yellowish tints of the wet sand glistening in the feeble rays of occasional sunlight. By a quarter past six the mountains were scarcely discernible, and a pale yellow glow seemed to be spreading gradually over the scene. Gleams of sunlight shining on pools gave the appearance, as seen from above, of glistening snakes curving in and out amid the patches of grass and verdure. This was the only touch of colour amid the increasing gloom.

I turned to look at the Sun through the Ecliptoglass (kindly provided for all the passengers by the Imperial Airways Company), and I could see that the moment of totality was fast approaching. Against such a cloud-laden sky there seemed little prospect of seeing the corona at its best, so I turned once more in the direction whence the oncoming shadow of the Moon was approaching. Even in that short interval I noticed that the gloom had sensibly increased, and the outlines of the mountains were practically invisible.

Darker and darker grew the sky, till suddenly

we were overwhelmed by the shadow of the Moon. Of a deep indigo purplish hue, which is simply indescribable, it hung like a funeral pall over the earth. Looking downward one could see but a solitary gleam from an electric lamp shining feebly in the darkness. The scene was most awe-inspiring. One can well imagine the terror inspired in those who do not know its meaning. Possibly, owing to the fact that we were watching it from a height, the shadow did not convey the impression of passing on swiftly, seeming rather to cling around us for a few seconds. Indeed, so impressed was I with the weird sight that I almost forgot to look in the opposite direction for the corona.

There is no denying the fact that the brief glimpse I had of the corona was undoubtedly disappointing. The halo—for so it appeared to me—was so hazy and indistinct that it was difficult to see the definite outline which seemed partly merged in the clouds beyond. There was no time to look for the narrow red rim around the edge of the Moon, denoting the chromosphere which remained partly uncovered, nor to see the red flames, for no sooner had I raised my binocular to my eyes than the corona vanished. Alas! I

had tarried too long in watching the marvellous shadow casting its gloom over the scene.

The darkness became so impenetrable that the pilot switched on the electric light so that he might get his compass readings. Doubtless this glare at the instant of totality made it impossible to obtain a good view of the corona, during the brief period of totality.

Some may consider the experience a failure, but for my part it was of the greatest interest to see this weird sight, concerning which so many impressive accounts have been written. It remains for an artist to portray that scene as it actually is, and for a poet to describe in fitting words, the changing shadow effects leading up to the startling climax, when for a few seconds the world seems buried beneath a wave of darkness.

As I have noted on former occasions, the normal light and colouring returns to the landscape within a very brief interval after totality, as compared with the time during which the gradual changes in colouring lead up to totality. By about twenty minutes to seven the Sun was shining brightly amid the clouds, though still partially eclipsed. Then, shortly after this tardy greeting to the many who had made such efforts to see it, the clouds gradually enveloped it in mist.

On our homeward journey we saw numberless soft, feathery-looking white clouds rising from the valleys beneath us, while overhead the sky was covered with clouds, so that for a while we made our way between them. Yet these clouds, which now rejoiced us with their beauty, were the same which had doubtless spoilt the eclipse scene for many watchers along the shadow track. And to think that seventy-two years must pass before the people in England will have another such opportunity!

Note

The following is an extract of letter received from Captain A. S. Wilcockson, the pilot of the aeroplane in which I observed the eclipse:

Air Port of London
Croydon.
13th July, 1927.

"My position at the time of totality was about 5 miles East of Preston, and my height 6,000 feet. My course was practically at right angles across the line of totality. I do not think the shadow was expected to come and go in a "flash" as the time of total eclipse was given as 23 seconds. I found this about correct."

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